Jeffrey H. Blum
Executive Vice President,
External & Legislative Affairs
Jeffrey.Blum@dish.com
(202) 463-3703

REDACTED—FOR PUBLIC INSPECTION

February 15, 2021

EX PARTE PRESENTATION

Ms. Marlene Dortch
Secretary
Federal Communications Commission
45 L Street NE
Washington, DC 20554

Re: IBFS File No. SAT-MOD20200417-00037; Call Signs: S2983 and S3018; Expanding Flexible Use of the 12.2-12.7 GHz Band, WT Docket No. 20-443

Dear Ms. Dortch:

DISH Network Corporation ("DISH") writes to provide the Commission with new information showing that the satellite system of Space Exploration Holdings, LLC ("SpaceX"), as proposed to be modified,[1] would violate applicable power limits and inflict harm on the millions of households receiving Direct Broadcast Satellite ("DBS") service from DISH throughout the United States in the 12.2-12.7 GHz band ("12 GHz Band"). Attached is a technical study (the "Telecomm Strategies Report"), commissioned by DISH and undertaken by well-respected non-geostationary satellite orbit ("NGSO") expert engineer Marc Dupuis of Telecomm Strategies, that analyzes the effect of SpaceX's requested Third Modification on DISH's DBS service.[2]

In short, the Telecomm Strategies Report concludes that SpaceX's system, as proposed to be modified, would sharply exceed the Equivalent Power Flux Density ("EPFD") limits established by the International Telecommunication Union ("ITU"), and incorporated by reference in the Commission's rules,[3] at the receive dishes used by DISH customers, in light of

---

[1] Application of Space Exploration Holdings, LLC for Modification of Authorization for the SpaceX NGSO Satellite System, IBFS File No. SAT-MOD-20200417-00037 (filed Apr. 17, 2020) ("Third Modification").

[2] This letter is accompanied by a request for confidential treatment to permit DISH to comply with a nondisclosure agreement, subject to which SpaceX has finally acquiesced in providing certain information to DISH. DISH is filing a redacted version of the attached Report for the public record.

[3] *See* ITU RR 22.5C, Table 22-1D; 47 C.F.R. §§ 25.108, 25.146, 25.284.

the inevitable reality that more than one satellite beam, and potentially 10 or more, can be expected to illuminate the same area in the same frequency at the same time.[4] To date, SpaceX has gotten away with a showing of compliance with these limits based on the fiction that only one beam will ever serve one area in one frequency. Assuming that SpaceX needs to use the 12 GHz band as SpaceX asserts,[5] that does not begin to account for the concentrated clusters of demand that an NGSO operator will be called upon to meet at acceptable service levels. It is furthermore out of touch with the more realistic analysis of many other NGSO systems, which estimate that the same area will need to be served by up to 40 co-frequency beams at the same time. The chasm between one and 40 is, of course, vast. The Telecomm Strategies Report estimates that the number of overlapping co-frequency beams, known as the "Nco," will reasonably range from two to 10 or more. DISH plans to request that the Commission obtain additional documentation from SpaceX to facilitate further evaluation, and will conduct and submit additional studies based on the information it receives.

Second, Telecomm Strategies has concluded that an additional detrimental impact on DISH consumers and their ability to receive DISH's service would result directly from the proposed modification, with its proposed decrease of the minimum elevation angle from 40° to 25° and the change in the power flux density ("PFD") mask. This "increase[] in "the potential for interference,"[6] has consequences both for the evaluation of SpaceX's modification under the prism of the public interest, and for its procedural treatment.

For these reasons, among others, the Commission should complete the above-captioned rulemaking before acting on SpaceX's Third Modification request.

Background. As the Commission is well aware, SpaceX has for many months refused to submit an EPFD analysis to demonstrate to the Commission and the public that SpaceX's NGSO Fixed-Satellite Service ("FSS") operations would not generate power levels beyond what a standard co-frequency DBS reference antenna in the 12 GHz Band could tolerate. In addition,

---

[4] Of course, NGSO licensees must operate "on a non-harmful interference basis to DBS," *see Expanding Flexible Use of the 12.2-12.7 GHz Band*, WT Docket No. 20-443, Notice of Proposed Rulemaking, FCC 21-13, ¶ 5 (Jan. 15, 2021). In fact, under international footnote 5.487A to the U.S. Table of Frequency Allocations, NGSO systems "shall not claim protection" from DBS, "irrespective of the dates of receipt by the Bureau of the complete coordination or notification information," and must "rapidly eliminate[]" any unacceptable interference they cause. 47 CFR § 2.106, n. 5.487A.

[5] DISH seriously questions the need of NGSO systems for the 12 GHz band in light of the ample other spectrum—some 15,050 megahertz—they are authorized to use. *See* DISH Network Corporation, *Spectrum Available to SpaceX Non-Geostationary Orbit Fixed-Satellite Service (NGSO FSS)* (July 14, 2020) (attached to Letter from Jeff Blum, DISH, to Marlene Dortch, FCC, IBFS File No. SAT-MOD-20200417-00037, RM-11768, at 7 (July 14, 2020)).

[6] *See* 47 CFR § 25.116(b)(1); Teledesic LLC, *Minor Modification of License to Construct, Launch and Operate a Non-Geostationary Fixed Satellite Service System*, Order and Authorization, 14 FCC Rcd. 2261, 2264 ¶ 5 (1999).

even after placing the onus on DISH to do SpaceX's EPFD analysis for it,[7] SpaceX repeatedly failed to provide DISH with sufficient information to verify that SpaceX's pending proposal to dramatically reduce the altitude of thousands of satellites will not disrupt DBS in the 12 GHz band. SpaceX finally provided DISH the underlying data files associated with SpaceX's Third Modification *only after* SpaceX's stonewalling was brought to the Commission's attention.[8] While falling short of a full accounting of the company's actual design and operation parameters, SpaceX's confidential files contain relevant orbital and radiofrequency parameters for the revised NGSO FSS system under consideration, as well as earth station and satellite effective isotropic radiated power ("EIRP") and PFD masks in the 14 GHz and 12 GHz bands.[9]

The effect of the beam convergence. Based on this recently disclosed information, DISH commissioned Telecomm Strategies to undertake a technical study of the Starlink system's EPFD compliance. The study confirms DISH's longstanding concerns that SpaceX's Third Modification cannot adequately protect DBS receivers operating in the 12 GHz Band. As DISH correctly anticipated even before review of the new data,[10] SpaceX's EPFD calculations appear to rely on an unrealistic input—namely, that SpaceX's constellation of satellites would have an "Nco" of one. As mentioned, NGSO operators use the term "Nco" to refer to the maximum number of beams in any one frequency channel used to serve customers at any one geographical location.[11] By using an Nco of one for customer links, SpaceX assumes that only one Starlink satellite will emit to any given point on the ground at once. Relying on this critical but deeply flawed assumption, SpaceX's calculations demonstrate—based on the data provided to date—that the Third Modification produces EPFD values that can protect existing DBS operations.

---

[7] *See* Letter from David Goldman, Director of Satellite Policy, SpaceX, to Marlene Dortch, Secretary, FCC, IBFS File No. SAT-MOD-20200417-00037, at 2 (filed June 29, 2020).

[8] *See, e.g.*, Letter from Trey Hanbury, Hogan Lovells US LLP, to Marlene Dortch, Secretary, FCC, IBFS File No. SAT-MOD-20200417-00037, *et al.*, at 1-7 (filed Sept. 25, 2020); Letter from Jeffrey Blum, Executive Vice President, External and Legislative Affairs, DISH Network LLC, to Marlene Dortch, Secretary, FCC, IBFS File No. SAT-MOD-20200417-00037, at 1 (filed Aug. 6, 2020) ("DISH August 6 Ex Parte"); Letter from Jeffrey Blum, Executive Vice President, External and Legislative Affairs, DISH Network LLC, to Marlene Dortch, Secretary, FCC, IBFS File No. SAT-MOD-20200417-00037, at 3-5 (filed July 14, 2020); Letter from Jeffrey Blum, Executive Vice President, External and Legislative Affairs, DISH Network LLC, to Marlene Dortch, Secretary, FCC, IBFS File No. SAT-MOD-20200417-00037, at 5-7 (filed June 16, 2020).

[9] Although DISH has had the private opportunity to evaluate SpaceX's claims of EPFD compliance based on information provided under a non-disclosure agreement, SpaceX still has not provided this information to the Commission or the public at large. Nor has SpaceX made own EPFD analysis available for public inspection.

[10] DISH August 6 Ex Parte at 2-4.

[11] "Nco" is synonymous with "nb_op_sat", which is the name of the value used in SpaceX's files and the ITU regulations.

But as the Telecomm Strategies study makes clear, the Commission has no reason to accept SpaceX's assumed Nco of one, and should not do so. The proper Nco could realistically be closer to four or six for user downlinks if SpaceX requires additional capacity to serve a given area, which seems likely, SpaceX has previously claimed it will not use more than one co-frequency satellite at a time to any one point on the ground. This assertion is dubious on its face because it ignores the high probability that two closely spaced user terminals could operate on two different co-frequency Starlink satellites, resulting in overlapping Ku-band beams providing service to a single area. Also unpersuasive is SpaceX's justification that it will use steerable beams.[12] Telesat, another NGSO FSS operator also deploying steerable beams, explained why: "a much higher [NCO] value [than one] needs to be used when running the EPFD validation software in order to capture the contributions to the EPFD down from a larger number of satellites, whether or not they are intentionally transmitting to this given location."[13] The likelihood of overlapping beams seems nearly certain, given that SpaceX will operate more than 4,000 satellites. Simple math dictates that a greater number of satellites will contribute more EPFD, even if those satellites do not intend to transmit intentionally to a given location.

Submissions from every other 12 GHz Band NGSO FSS applicant and licensee confirm that SpaceX's Nco of one does not correspond to operational realities and should be rejected by the Commission. Unlike SpaceX, other NGSO applicants analyzed their EPFD compliance based on their actual system design parameters. NGSO operators select these values to ensure that the ITU's software captures the additional EPFD emissions caused by the sidelobe performance of other visible satellites outside the GSO exclusion zone. In the 2016 processing round, for example, Kepler's initial 140-satellite constellation used an Nco of four.[14] So did Theia's 112-satellite constellation.[15] New Satellite Spectrum used three as its Nco for its 15-satellite system.[16] OneWeb presented an Nco of forty for its 720- satellite constellation,[17] a figure that OneWeb used again for the 47,844-satellite system it proposed in the 2020 processing

---

[12] *See* Letter from David Goldman, Director of Satellite Policy, SpaceX, to Marlene Dortch, Secretary, FCC, IBFS File No. SAT-MOD-20200417-00037, at 2 n.9 (filed June 29, 2020).

[13] *See* Telesat, IBFS File No. SAT-MPL-20200526-00053, Technical Information at 15 (filed May 26, 2020).

[14] *See* Kepler, IBFS File No. SAT-PDR-20161115-00114, Technical Narrative at 25 (filed Nov. 15, 2016).

[15] *See* Theia, IBFS File No. SAT-LOA-20161115-00121, Technical Narrative, Appendix 1 at 5- 6 (PDF p. 62-63) (filed Nov. 15, 2016).

[16] *See* New Spectrum Satellite, IBFS File No. SAT-APL-20200526-00060, Narrative Attachment at 56-57 (filed May 26, 2020); e-Submission of Satellite Network Filings, ITU, https://bit.ly/335Xtww (Feb. 22, 2018 coordination request for "V-GEO 1" filing).

[17] *See* EPFD data and EPFD examination results, ITU, https://bit.ly/2EwcXzL (initially filed Nov. 18, 2017 and updated with no change to Nco on Jan. 23, 2018 and Dec. 10, 2019 inputs for "L5" filing); OneWeb, IBFS File No. SAT-LOI-20160428-00041, Technical Narrative at A1-5 (filed Apr. 28, 2016).

round.[18] The only two 12 GHz Band NGSO FSS operators that appear to have used an Nco value of one involve special circumstances not remotely present in SpaceX's system.[19]

The Telecomm Strategies Report explains that, assuming SpaceX's asserted need for the 12 GHz band, SpaceX's Nco would realistically be as high as ten or more. It is easy to see why: one SpaceX beam with 240 MHz bandwidth could support about 200 to 300 Mbps of user traffic. As the report notes:

> This one beam would thus likely support no more than 10 users actively requesting service in one area at a busy hour, providing 30 Mbps peak data rate to each (10 users times 30 Mbps equals 300 Mbps). But in reality, there are probably 50 to 100 users that are sharing that same 300 Mbps pipe, using time-division multiplex. If the area being served . . . is a large remote village, or a busy port without terrestrial infrastructure, or even a cruise ship, or more ships passing each other, the number of users seeking simultaneous access, especially during early evening busy hours, could easily be counted in the thousands.[20]

The following chart, reproduced from the Telecomm Strategies Report, illustrates the impact of beam convergence vividly. **It shows the geostationary consumer dishes, including those of DISH customers, at which EPFD levels would violate the Commission's limits for any amount of time:**

[18] *See* EPFD data and EPFD examination results, ITU, https://bit.ly/2EwcXzL (Aug. 6, 2019 inputs for "THEO" filing).

[19] Karousel intends to deploy only 12 satellites globally and will operate them in highly inclined elliptical orbits so that only one satellite will be active over North America at any given point in time. *See* Karousel, IBFS File No. SAT-LOA-20161115-00113, Application at 4 (filed Nov. 15, 2016). Kepler's second, separate system (2020 processing round) likewise will only serve high latitude areas above 55°N, which is well north of the border between the continental United States and Canada. *See* Kepler, IBFS File No. SAT-PDR-20200526-00059, Exhibit B at 4-6 (filed May 26, 2020). Kepler will also use low elevation angles and exclusion masks to protect GSO systems. The unique configurations of these two systems may make an assumed value of one for the Nco parameter conceivable for Karousel and Kepler in circumstances that are simply absent from SpaceX's system.

[20] *See* Telecomm Strategies Report at 21-22.

Run/Status:	SpaceX	Baseline	Nco = 2	Nco = 4	Nco =10
EFPDup	PASS	PASS	FAIL	FAIL	FAIL
EPFDdn FSS 0.6m	PASS	PASS	FAIL	FAIL	FAIL
EPFDdn FSS 1.2m	PASS	PASS	FAIL	FAIL	FAIL
EPFDdn FSS 3m	PASS	PASS	PASS	FAIL	FAIL
EPFDdn FSS 10m	PASS	PASS	PASS	PASS	PASS
EPFDdn BSS 0.3m	PASS	PASS	PASS	PASS	FAIL
EPFDdn BSS 0.45m	PASS	PASS	FAIL	FAIL	FAIL
EPFDdn BSS 0.6m	PASS	PASS	FAIL	FAIL	FAIL
EPFDdn BSS 0.9m	PASS	PASS	PASS	FAIL	FAIL
EPFDdn BSS 1.2m	PASS	PASS	FAIL	FAIL	FAIL
EPFDdn BSS 1.8m	PASS	PASS	PASS	FAIL	FAIL
EPFDdn BSS 2.4m	PASS	PASS	PASS	FAIL	FAIL
EPFDdn BSS 3m	PASS	PASS	PASS	PASS	FAIL
EPFDis	PASS	PASS	PASS	PASS	PASS

The following chart from the report moreover shows which dishes will suffer excess EPFD levels 10% of the time, and quantifies that excess above the limit in each case:

EPFD (10%)	SpaceX	Baseline	Nco =2	Nco =4	Nco =10
Up	0.5	0.35	-2.1	-4.5	-8.0
Dn FSS 0.6	1.0	1.0	-0.5	-2.7	-5.3
Dn FSS 1.2	1.2	1.4	-0.3	-2.0	-4.7
Dn FSS 3.0	2.5	2.6	1.5	-0.1	-2.5
Dn FSS 10.0	7.0	7.0	5.8	2.5	2.0
Dn BSS 0.3	4.0	4.0	2.0	0.2	-1.8
Dn BSS 0.45	1.0	1.0	-1.0	-2.8	-4.8
Dn BSS 0.6	1.5	1.5	-0.4	-2.2	-4.5
Dn BSS 0.9	2.1	2.2	1.2	-1.3	-3.8
Dn BSS 1.2	1.3	1.3	-0.1	-2.0	-4.5
Dn BSS 1.8	2.8	2.8	1.2	-0.7	-3.3
Dn BSS 2.4	3.0	3.0	1.6	-0.4	-2.8
Dn BSS 3.0	4.0	4.0	2.5	1.0	-1.3
IS	2.3	2.3	2.3	2.3	2.3

For these reasons, the Telecomm Strategies Report concludes that SpaceX's arbitrary Nco of one materially understates the level of interference that DBS receivers can expect to encounter. Increasing the Nco even to a value of *two* would exceed EPFD limits for small antennas, such as those used by DISH in its Broadcast Satellite Service ("BSS") and FSS antennas. Increasing the Nco to four or 10—which is more realistic given the number of satellites with co-frequency overlapping beams over an area where a geostationary earth station is located—would result in SpaceX's exceeding the ITU's EPFD limits in nearly all circumstances. When Nco is set at four, the EPFD would increase by at least one to three dB. At an Nco of 10, the theoretical worst-case scenario analyzed in which SpaceX employs a large number of satellites to boost capacity or throughput in a given area, Starlink's EPFD would increase by a value of at least five dB. And, Telecomm Strategies' conclusions are conservative. The value of excess dB based on an increased Nco could be much greater depending on more realistic assumptions about the Starlink system's irregular plane altitudes and inclination angles.

The effect and implications of the modification. Finally, the Telecomm Strategies Report assesses and quantifies the effect on DISH customers and other geosynchronous systems that would result from the proposed Third Modification. The Report compares the EPFD curves for the original filing and the modification for two antennas—the 45cm BSS and 1.2m FSS dishes—and concludes: "the MOD-3 constellation, with its reduced minimum operational elevation angle, shows a typical increase of about 2 to 3 dB in the time percentages below about 50% for the 45cm GSO BSS receive earth station. For the 1.2m GSO FSS earth station, the increase is even more significant, from 1 to 8 dB, in the time percentages below 10%. This clearly shows that this 3rd Modification will cause more interference into GSO networks than the already-authorized NGSO system."[21]

This has serious ramifications for SpaceX's modification request. First, as the Commission has explained, under the rule governing license modifications, "[i]f a modification would worsen the interference environment, that would be a strong indication that grant of the modification would not be in the public interest."[22] As the Commission has also pointed out:

> This criterion is analogous to the criteria used in Section 25.116 of the Commission's rules to determine whether an amendment to a pending NGSO-like space station application is "major" and thus necessitates consideration outside of the processing round of the original application. 47 CFR § 25.116. Under Section 25.116, an amendment is "major" if, among other things not relevant here, it "increases the potential for interference, or changes the proposed frequencies or orbital locations to be used." 47 CFR § 25.116(b)(1). An amendment will not be considered major, however, if resolves frequency conflicts with authorized stations or other pending applications but does not create new or increased frequency conflicts."[23]

[21] Telecomm Strategies Report at 10.

[22] Space Exploration Holdings, LLC, *Request for Modification of the Authorization for the SpaceX NGSO Satellite System*, Order and Authorization, 34 FCC Rcd. 2526, 2529 ¶ 9 (April 26, 2019).

[23] *Id.* 2529 ¶ 9 n. 32.

Second, the distinction between "major" and "minor" impacts the application's procedural treatment. As the Commission has found, "if the modification application were to present significant interference problems, we would treat the modification as a newly filed application and would consider the modification application in a subsequent satellite processing round."[24] As a number of NGSO proponents have argued, the significantly increased interference risk and the radical reconfiguration of SpaceX's Third Modification warrant evaluation of the proposed constellation in the 2020 processing round rather than a grant of the modification request.[25]

Furthermore, because of the proposed modification's impact, the Commission should not

---

[24] Teledesic LLC, Order and Authorization, 14 FCC Rcd. 2261, 2263 ¶ 5 (1999); *see also* Geostar Positioning Corporation, Order and Authorization, 6 FCC Rcd. 2276, 2278 ¶ 15 (1991) ("[T]he modified system is so significantly different from the system as authorized that it must be considered as a new system and should not become the new 'baseline' for coordination purposes without the benefit of a new RDSS processing group.").

[25] *See* Reply of Kuiper Systems, Inc., FCC File No. SAT-MOD-20200417-00037, at 11-14 (August 7, 2020) ("SpaceX's modification application (filed during the window for the 2020 Processing Round) significantly impacts the NGSO FSS interference environment for all systems in the 2016 and 2020 Processing Rounds. These significant interference impacts justify including the redesigned constellation in the 2020 Processing Round if the space safety concerns warranting denial can be overcome."); Kuiper Systems, Inc. Petition to Deny and Comments, FCC File No. SAT-MOD-20200417-00037, at 28-30 (July 13, 2020) ("SpaceX's prior modification requests collectively, with this Third Modification, adversely impact the operating environment; accordingly, the entire SpaceX constellation should be considered in the 2020 Processing Round."); *see also* Reply Comments of Viasat Corp., RM-11861 - Modernization of Section 25.117 of the Commission's Rules for Modifications of NGSO FSS Systems in the New Space Age, at 8 (Sept. 1, 2020) ("SpaceX's proposed modification does not even remotely resemble that of its authorized system."); Reply of SES Americom, Inc. and O3B Limited, FCC File No. SAT-MOD-20200417-00037, at 11-17 (August 7, 2020) ("if a modification presents 'significant interference problems' the Commission will 'treat the modification as a newly filed application and would consider the modification application in a subsequent satellite processing round.'"); SES Americom, Inc. and O3B Limited, Petition to Deny or Defer, FCC File No. SAT-MOD-20200417-00037, at 15 (July 13, 2020) ("…the reconfiguration would significantly increase interference to O3b and make SpaceX more vulnerable to interference from O3b and other NGSO operators, leading to the potential for many more cases that could require band-splitting…. [a]t a minimum, under the precedent established in Teledesic the Commission must determine that the adverse effect on the NGSO interference environment caused by the proposed changes requires that the Application be considered as effectively a re-filing of the SpaceX system proposal that must be incorporated into the Ku/Ka-band NGSO processing round that closed in May."); Letter from Suzanne Malloy, Vice President, SES Americom, Inc. and O3B Limited, to Marlene Dortch, Secretary, FCC, FCC File No. SAT-MOD-20200417-00037 (Sept. 10, 2020) ("The NGSO interference, GSO protection, and space safety issues raised by the SpaceX redesign require the Commission to treat the system as newly filed."); Letter from Suzanne Malloy, Vice President, SES Americom, Inc. and O3B Limited, to Marlene Dortch, Secretary, FCC, FCC File No. SAT-MOD-20200417-00037 (Nov. 20, 2020) ("To preserve the integrity of the NGSO processing round framework, the Commission must treat the redesigned SpaceX and ViaSat systems as newly filed.").

act on it until it concludes its recently issued rulemaking proceeding regarding the 12 GHz band.

The Telecomm Strategies Report is attached for the Commission's review. Please feel free to contact me with any questions regarding this letter or the technical submission.

/s/ Jeffrey H. Blum
Jeffrey H. Blum

EPFD Assessment of SpaceX into DISH Ku-band GSO networks

Qualifications

Marc Dupuis joined Telecomm Strategies LLP in April 2020 after retiring from OneWeb, where he directed the Spectrum team, responsible for securing ITU rights to the spectrum/orbit, coordination of the system. Before joining OneWeb, Mr. Dupuis spent twelve years at Industry Canada, in progressively more senior roles, his last was Director General for the Spectrum Engineering Branch. He directed the regulatory planning and engineering of the radio spectrum and telecommunication for the benefit of Canadians. Before accepting a position in the federal government, Mr. Dupuis worked eighteen years in the private sector, first with Telesat Canada and then as the Director of the Canadian office for Teledesic, a start-up satellite company.

Telecomm Strategies is a very experienced and highly capable engineering consulting firm which specializes in satellite communications, including system design with a particular emphasis on the international regulatory aspects that are so crucial to this business. Typical assignments involve the application of sound engineering and business judgment, coupled with a detailed knowledge and experience of the international and domestic satellite communications business and the regulations that govern it. Telecom Strategies associates collectively possess more than 150 person-years of experience in this field.

Summary and Abstract

This study was conducted to assess the equivalent power flux density (EPFD) levels that can be expected from the proposed SpaceX NGSO FSS constellation into DISH GSO FSS and BSS networks, based on the characteristics, configuration and technical elements provided by SpaceX in its request to the FCC for a 3rd modification to its authorized system.[1] In short, high-demand, high-volume areas will realistically require more than one of the system's co-frequency beams, contrary to SpaceX's one-beam-at-a-time claim, and these converged beams would likely exceed EPFD limits and have a detrimental impact on the receive dishes of DISH customers and the uplinks of many DISH satellites.

As DISH communicated to the Commission before,[2] the favorable finding that SpaceX obtained for its Norwegian STEAM-1 filing and its USA USASAT-NGSO-3A-R filings was a result of the company's assertion that its NGSO satellite system will *never* have two co-frequency overlapping beams from its multitude of satellites, notwithstanding the traffic demand that one geographical area may require. But that assertion does not dovetail with real life and the need of SpaceX to provide acceptable levels of service in high-demand, high volume areas. It is inconceivable that SpaceX would decide to offer sub-par service to certain populated areas, just because in its filings and its FCC application, it purported to limit transmission to any and all spots on the Earth, to a single beam on a given channel, from a single satellite. Furthermore, as DISH has observed, SpaceX's assumption is sharply at odds with the more realistic practice of many other NGSO FSS systems, which have used much

[1] IBFS File No. SAT-MOD-20200417-00037

[2] *See* DISH letter to Marlene Dortch, FCC, dated August 6, 2020

higher figures, up to 40, in their EPFD calculations for the number of satellites providing coverage of a single spot.[3]

While their application does not disclose the number of satellite user beams in Ku-band, nor the frequency assignment and channelization plan of these multiple satellite beams, there is one revealing point, in that the SpaceX blanket earth station authorization [4] indicates emission designators of 240 MHz bandwidth. This is also consistent with the "as received" file for the STEAM-1 satellite filing at the ITU.[5] If the assertion made by SpaceX was to be taken at face value, it would mean that one spot would be limited at each instant in time to that single 240 MHz carrier, if other beams on that satellite are serving other areas. It would seem an ill-advised business decision to limit the capacity in high demand areas, such as large remote or rural towns, to potentially a single 240 MHz carrier. On the other hand, as this study demonstrates, if two or more satellites provide co-frequency coverage of the same spot on the Earth simultaneously, *the ITU Radio Regulations and FCC EPFD limits will be exceeded*.

Should the business demand in one area require more than two co-channel beams from various satellites, these EPFD limits could be exceeded quite significantly.

Further contributing to the exceedance over the EPFD limits is the effect of beams from neighboring areas, another factor that SpaceX seems to not have taken into account. The EPFD levels we have calculated would be further exacerbated by the additional EPFD caused by these beams' sidelobes, since the ITU software does not fully capture that effect.

Finally, an additional detrimental impact is due to the proposed modification. We believe that the EPFD levels for the modified constellation (3rd MOD), and therefore the extent to which these levels exceed the EPFD limits, will actually be higher than the values for the originally filed constellation configuration and the first two modifications.

Introduction

Overview of Approach

This study assesses the EPFD levels that can be expected from the proposed SpaceX NGSO FSS constellation into DISH GSO FSS and BSS networks, based on the characteristics provided by SpaceX in its Request to the FCC for a 3rd modification to its authorized system.

The main change proposed in this 3rd MOD request is to consolidate all SpaceX satellite orbits in the 540 to 570 km range, thereby reducing the altitude of several of the authorized orbits from their originally intended altitudes, which were 1110 km, 1130 km, 1275km and 1325km to much lower orbital heights.[6] In addition, this proposed 3rd modification proposes to reduce the minimal operational elevation angle from 40° down to 25°, for all satellites, which can also impact the EPFD

---

[3] *Idem; some operators, like Telesat, remarked that although their system is designed so that only one satellite would transmit to a given location, they recognize the lacuna in the ITU-R Recommendation S.1503-2 and its software implementation, which necessitate a higher value to ensure capturing the sidelobe energy of other co-frequency beams from other satellites.*

[4] *See* https://fcc.report/IBFS/SAT-MOD-20200417-00037/2318032

[5] *See https://www.itu.int/ITU-R/space/asreceived/Publication/AsReceived*

[6] SpaceX's MOD-1 and MOD-2 had already reduced the orbital height of the 1150km orbit to 550km and reduced the number of satellites in that shell from 1600 satellites (32 * 50) to 1584 (72 * 22).

levels into GSO networks. This study does not purport to fully quantify the increase in potential interference resulting from the proposed changes. Instead, the study focusses on whether the ITU, and by reference the Commission's, EPFD limits are met or exceeded. The latter really depends on the key assumptions used in the study.

To gain a better understanding of potential impact of SpaceX EPFD into GSO FSS and BSS networks, the following analysis was conducted using the TransFinite VisualyseEPFD^{tm} software.

The data files required to run EPFD studies are composed of pairs of MS-Access (.mdb) files:

1) SRS database: contains the essential orbital and RF parameters for the NGSO system under consideration; and,
2) Masks database: contains the earth station EIRP masks, satellite EIRP masks and/or satellite PFD masks corresponding to the portion (e.g., band of operation) of the NGSO system in the SRS.

These file pairs were provided by SpaceX to DISH as listed below. Since this study concentrates only on Ku-band EPFD, the Ka-band files were not used for this analysis.

SRS_10p70-11p70_FSS_IS	2,640 KB	Mask_10p70-11p70_FSS_IS	54,044 KB
SRS_11p70-12p75_BSS_FSS_IS	3,016 KB	Mask_11p70-12p75_BSS_FSS_IS	54,044 KB
SRS_12p75_13p25_UL	2,860 KB	Mask_12p75_13p25_UL	22,720 KB
SRS_13p75-14p00_UL	2,684 KB	Mask_13p75-14p00_UL	29,912 KB
SRS_14p00-14p50_UL	2,664 KB	Mask_14p00-14p50_UL	25,216 KB
SRS_17p30-17p70_UL	2,824 KB	Mask_17p30-17p70_UL	31,036 KB
SRS_17p70-18p60_FSS_IS	2,888 KB	Mask_17p70-18p60_FSS_IS	31,036 KB
SRS_19p70_20p20_FSS	2,724 KB	Mask_19p70-20p20_FSS	31,036 KB
SRS_27p50-30p00_UL	2,824 KB	Mask_27p50-30p00_UL	31,036 KB

The main files used in this analysis include the following:

[SRS/Mask]_11p70-12p75_BSS_FSS_IS:	used for EPFDdn into BSS and FSS as well as EPFDis
[SRS/Mask]_14p00-14p50_UL:	used for EPFDup into FSS uplinks

It is understood that the EPFDdn/EPFDis file in the 10.7-11.7 GHz range would yield similar results to the one used in this assessment for the adjacent band (11.7-12.75 GHz), so it was not deemed worth repeating the study. Similarly, as for interference from the SpaceX uplinks into the DISH satellites receiving uplinks, the expectation for the 12.75-13.25 GHz and 13.75-14 GHz uplink bands would be EPFD results that are very similar to the main 14-14.5 GHz band used by most FSS systems including DISH's FSS networks. DISH BSS satellites use the 17.3-17.8 GHz feeder link (uplink) band, and interference would be slightly less for this higher frequency range, but, while this has not been specifically studied, would still likely exceed the EPFD limits, when two or more SpaceX earth stations transmit from the same location to two different NGSO satellites.

In order to compare our results, we have performed our baseline scenario for the proposed 3rd FCC MOD (satellites at 540, 550, 560 and 570km orbit) using the same parameters as those provided by SpaceX to the FCC as part of its application for a 3rd Modification ("3rd MOD"). SpaceX has provided to DISH the pertinent SRS and Masks files for this 3rd modification, and we assume that these are identical to the ones they supplied to the FCC, although this was not verified. The results were plotted for each of EPFDup, EPFDdn (for all FSS and BSS receive antenna sizes) and EPFDis.

In all the ITU SRS files provided by SpaceX to DISH for the proposed 3rd modification, one key observation is that the SpaceX constellation is purported to operate with a single satellite providing service to a given geographical point on a given channel, so that there would never be overlapping co-frequency Ku-band user beams providing service to a given area, even in cases where two closely spaced user terminals could receive service from two different satellites. Similarly, every spot is assumed to have a single earth station transmitting to only one satellite. We find that this over-simplistic approach yields EPFD levels that, while meeting the ITU limits, do not represent a realistic deployment, especially considering the very large number of satellites in the proposed SpaceX constellation. Furthermore, the limited geographic footprint available to each satellite, which is significantly reduced as a result of the large GSO exclusion angle employed by SpaceX,[7] provides less space to separate the multiple user beams of all satellites with overlapping coverage areas. The predicted EPFD levels could also be higher in reality as compared to the simulations, because of the algorithm employed in Recommendation ITU-R S.1503-2 and included in the ITU and TransFinite software, whereby emissions from the sidelobe (or potentially even the main beam) from nearby satellites serving areas close to the GSO FSS/BSS victim earth station could also contribute EPFD, but that is not computed by the software. Indeed, the software, as per the ITU S.1503-2 algorithm, only calculates the contribution of those NGSO satellites that are located inside the exclusion zone of the GSO earth station (which is always far-sidelobe low-level emissions from the NGSO satellite) plus a user-defined number of co-frequency emissions (main beam PFD levels) from satellites located outside the GSO earth station exclusion zone. This user-defined parameter, sometimes referred to as Nco, or alternatively as Nbr_op_sat as per the Recommendation S.1503, is provided as an input parameter by the NGSO operator in the corresponding SRS databases. It is not validated or checked by the ITU Radiocommunication Bureau.

Therefore, we first assessed the EPFD for a "baseline" scenario, using the SRS data file and masks as supplied by SpaceX, and using their stated Nco equal to a single co-frequency satellite serving a given area. Our results match the curves provided by SpaceX in their FCC 3rd MOD application.

After running a baseline scenario using the data provided by SpaceX for its proposed 3rd FCC MOD, we then modified the "Nco" field in each of the SRS data files to assess the impact of increasing the number of satellites that can transmit co-frequency to a given location (where the victim GSO earth station was placed). We have used Nco of 2, 4 and 10 to test the sensitivity of EPFD levels for each of these scenarios. We did not change any other parameter for these simulations, only the number of co-frequency beams providing service to a given point.

For all of our studies, we have used the Recommendation ITU-R S.1503-2 default settings, which estimate the location of the GSO earth station and its GSO satellite using an algorithm called the "worst-case geometry" or "WCG".[8] It is well known that this WCG algorithm works well for homogeneous NGSO constellations where plane altitudes and inclination angles are constant, and satellite plane spacings, or RAAN, are equally spaced, but less well when these characteristics are

---

[7] In the Ku-band, SpaceX utilizes 18° GSO arc avoidance, so there is 36°-wide band as measured at the satellite that is unusable for each satellite relative to a 114°-wide coverage area, above the minimum 25° elevation angle, resulting in 30% loss of that coverage area.

[8] See Recommendation ITU-R S.1503-2, Part D, Section D.3.3

not met. They are not met for the SpaceX constellation -- neither the originally filed system, nor the proposed 3rd FCC Modification. As a result, we believe that this WCG may yield unduly optimistic EPFD levels; nevertheless, to keep the analysis simple and to obtain results consistent with the analysis performed by SpaceX, we have used the default WCG algorithm of the EPFD software.

SpaceX NGSO Constellation Parameters used for EPFD Calculations

The SRS databases provided by SpaceX gives the constellation parameters as per Table 1.

Orbit ID	Total planes	Satellites per plane	Height (km)	Inclination (°)
1 – 72	72	22	540	53.2
73 – 144	72	22	550	53.0
145 – 148	4	43	560	97.6
149 – 154	6	58	560	97.6
155 – 190	36	20	570	70.0
	190	Total number of satellites = 4 408		

Table 1: Constellation Orbit Parameters

It should be noted that the original SpaceX FCC application was for 4425 satellites, which was reduced to 4409 satellites in the first MOD, but with orbital shells at 550 km, 1110km, 1130km, 1275km and 1325km altitudes.

The key parameters for EPFD assessment are contained in five tables in the SRS data files:

1) The “non-geo” table provides:
    a) for computing EPFDup, the number of satellites that each unique earth station (grid created by the software) can communicate with, on a given frequency (“Nbr_sat_td”);
    b) the density of earth stations in a GSO footprint, in units per km^2 (note that for FDM-TDMA systems, the density is equal to 1 over the average distance squared);
    c) the average distance between co-frequency earth stations in km;
    d) the type and size of the GSO exclusion zone.

[BEGIN CONFIDENTIAL]

[END CONFIDENTIAL]

2) The “sat-oper” table provides:
    a) the latitude range (negative latitude to positive latitude) of operation;
    b) the maximum number of satellites that can transmit co-frequency to a single point on the ground (“Nco” or “nbr_op_sat”).

[BEGIN CONFIDENTIAL]

[END CONFIDENTIAL]

3) The “mask_info” table provides:
   a) a mask ID, which is a reference to the mask data that can be found in the corresponding Mask database;
   b) the frequency range (min/max) for which the mask is applicable;
   c) Mask use or flag, which indicates whether the mask is satellite EIRP [S], earth station EIRP [E] or satellite PFD [P] which are used to compute EPFDis, EPFDup and EPFDdn, respectively;
   d) Mask type, which is one of four types, but only [O] for EIRP and [Z] for PFD in satellite az/el coordinates are used in these filings.

[BEGIN CONFIDENTIAL]

[END CONFIDENTIAL]

4) The “mask_link1” table provides links for each satellite in the constellation, using its orbit_id and sequence numbers to a mask ID, as defined in “mask_info”, which is a reference to the mask data that can be found in the Masks database.

[BEGIN CONFIDENTIAL]

[END CONFIDENTIAL]

5) The “mask_lnk2” table provides the sequence number of the associated earth station.

[BEGIN CONFIDENTIAL]

[END CONFIDENTIAL]

Another relevant aspect of these databases are the masks themselves. For this filing, they are too numerous to show here, but an example is provided for one PFD mask in graphic form. Figure 1(a) shows the 3D mask for the 540km orbit 3rd MOD application, with satellite AZ (east-west direction if the satellite were to operate at 90° polar orbit) in one axis, satellite EL (north-south direction) on the other axis, and the PFD value as the third axis. This mask is for a SpaceX satellite at 35°N. Figure 1(b) shows one of the PFD masks for the original STEAM-1 filing (for a satellite at 1150 km orbit) taken from the ITU web site, which we believe is the same as the corresponding mask provided to the FCC for the original SpaceX application.

[BEGIN CONFIDENTIAL]

[END CONFIDENTIAL]

Figure 1(a): SpaceX 3rd Mod PFD mask (satellite latitude is 35°N @ 540km orbit)

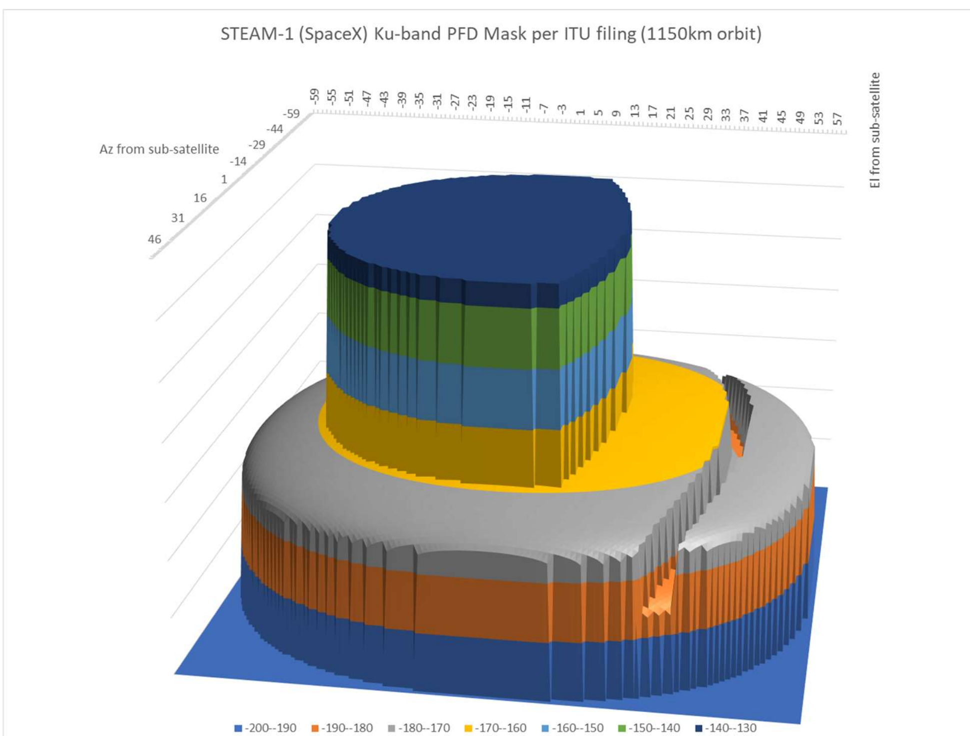


Figure 1(b): STEAM-1 SpaceX PFD mask (satellite latitude is 35°N at 1150km orbit)

A few interesting observations, which are entirely consistent with the expected performance of such PFD masks:

- The maximum PFD (-136 dBW/m^2 per 40-kHz) occurs in the southern side of the visible portion of the Earth, as expected for a satellite located at 35° North which needs to protect GSO receive earth stations located North of the sub-satellite point;
- Outside the service area, which corresponds to a minimum earth station elevation angle of 25 degrees (for the 3rd MOD) and 40 degrees (for the original STEAM-1 application), the PFD declines quickly to a value of -170 dBW/m^2 per 40-kHz, or less;
- In the direction corresponding to the projection of the GSO arc unto the Earth's surface as depicted in satellite Az-EL coordinates, the PFD is significantly reduced within the 22° GSO exclusion zone, again to levels around -170 dBW/m^2 per 40-kHz;
- In the case of the original STEAM-1 application, the mask is further reduced by another 10 dB approximately +/-2° around the projection of the GSO arc, as described by SpaceX in its original FCC application.[9]

A simplified PFD mask can be drawn by taking one cut in Azimuth and plotting PFD as a function of satellite elevation (sat EL) angle, as shown in Figure 2 below, this time for a satellite exactly over the Equator (Latitude = 0°). Figure 2(a) shows the PFD mask for the 3rd MOD application, whereas Figure 2(b) gives the same for the STEAM-1 ITU application.

[BEGIN CONFIDENTIAL]

[END CONFIDENTIAL]

Figure 2(a): SpaceX 3rd Mod PFD mask (satellite latitude is 0°N @ 540km orbit)

[9] *See* SAT-LOA-20161115-00118 (filed Nov. 15, 2016), SpaceX 2016 Application, in Annex 1, at page Annex 1-2

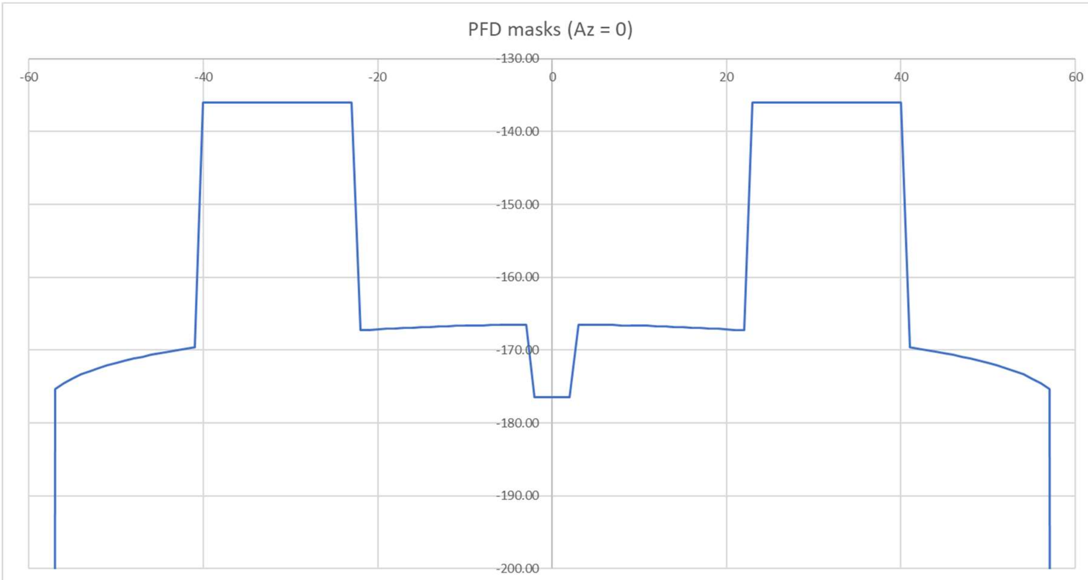


Figure 2(b): STEAM-1 SpaceX PFD mask (satellite latitude is 0°N at 1150km orbit)

In the figure above, the PFD mask is symmetrical about the Equator, with two "service zones" corresponding to satellite EL angle between the edge of the GSO satellite exclusion zone, which is 18° (satellite EL angle) for the 3rd MOD 540km orbit satellite, whereas the exclusion zone was 22° for the original STEAM-1 1150km orbit satellite.

The outer-bound edge of the service area corresponds to the minimum operational elevation angle, which is 25° for the 3rd MOD (540km orbit) satellite, so in satellite elevation coordinates this translates to 56.7° from the satellite NADIR, whereas for the original STEAM-1 (1150km orbit) satellite, the edge of service was defined by a 40° minimum operational elevation angle, which corresponds to 40.5° from the satellite NADIR.

The PFD then rolls off smoothly until the edge of visibility (0° elevation angle), which is 67.2° in satellite off-axis angle for an orbit altitude of 540km and 57.9° for the 1150km orbit satellite.

We can also see the deeper notch near the GSO arc in the case of the STEAM-1 original filing.

It is our understanding that these PFD mask do not represent any individual satellite beam operating on a given RF channel, but all possible positions of such steerable beams. It is not clear whether this PFD mask represents a composite of all co-frequency beams on a given satellite, as no information was provided in the FCC Applications to determine the performance of each beam, the inter-beam distance, or even the number of co-frequency beams that can be transmitted by a given satellite.

Comparison of EPFD Curves for Original Constellation and MOD-3 Constellation

Figure 3 provides a comparison of the ITU EPFD curves for the STEAM-1 satellite filing and the SpaceX-supplied EPFD curves for two selected antennas: the 45cm BSS and the 1.2m FSS. As can be seen from these figures, the MOD-3 constellation, with its reduced minimum operational elevation angle, shows a typical increase of about 2 to 3 dB in the time percentages below about 50% for the 45cm GSO BSS receive earth station. For the 1.2m GSO FSS earth station, the increase is even more significant, from 1 to 8 dB, in the time percentages below 10%. This clearly shows that this 3rd

Modification will cause more interference into GSO networks than the already-authorized NGSO system. The combined effect of the reduced altitude and extended service area (reduced minimum elevation angle) with the removal of the 10-dB notch in the PFD mask for the 3rd Modification NGSO system (see Figure 2) likely all contribute to the increased EPFD.

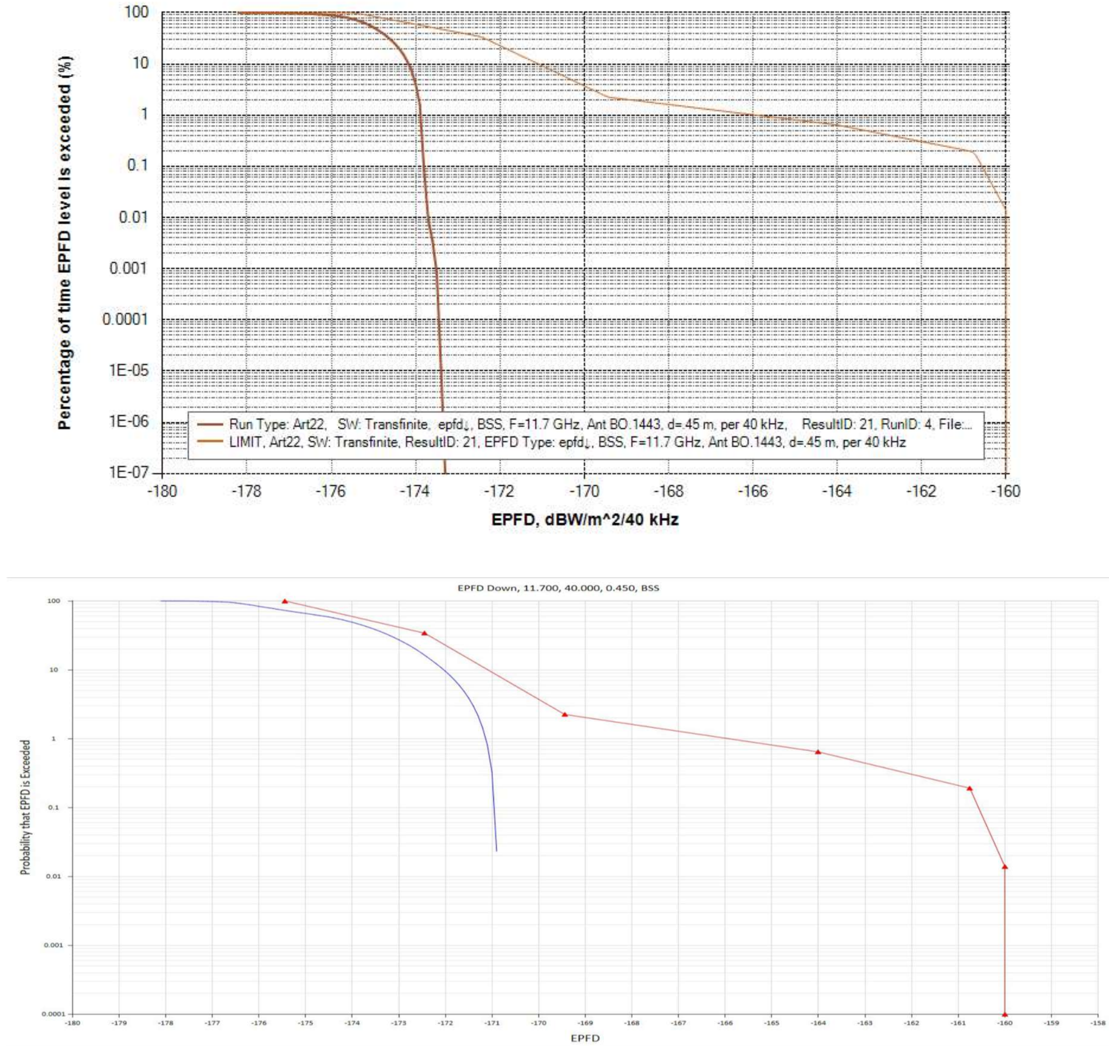
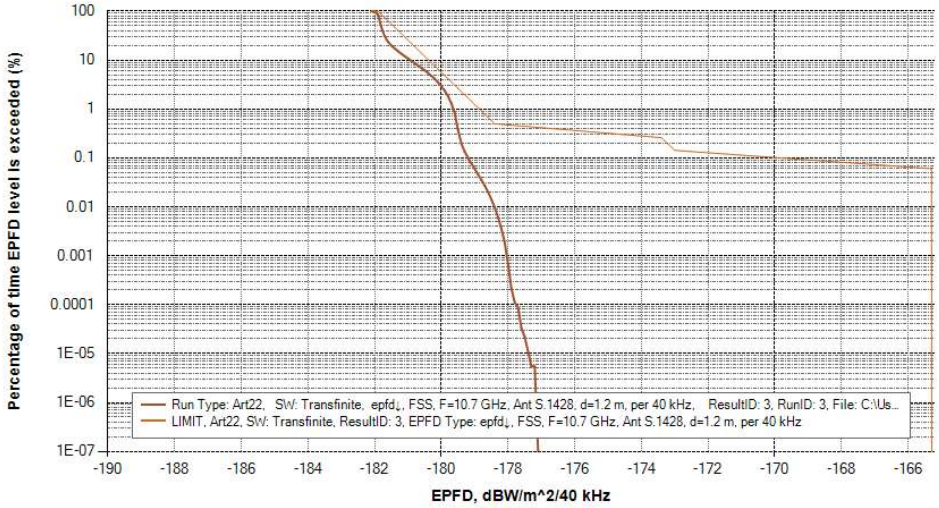


Figure 3a: EPFD Comparison between Original STEAM-1 filing (Above) and SpaceX 3rd FCC Modification (Below) (45cm GSO BSS receive earth station)



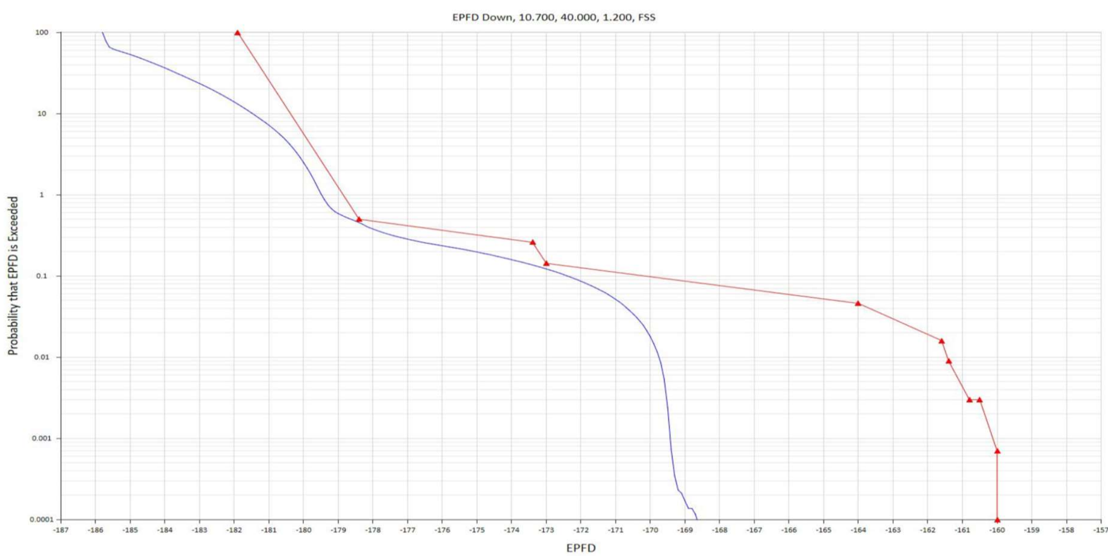


Figure 3b: EPFD Comparison between Original STEAM-1 filing (Above) and SpaceX 3rd FCC Modification (Below) (1.2m GSO FSS Receive Earth Station)

GSO Earth Station Antenna Patterns used for EPFD Calculations

Figure 4 plots the various earth station antenna gain patterns for all GSO FSS (Recommendation ITU-R S.1428) and GSO BSS (Recommendation BO.1443) earth stations.

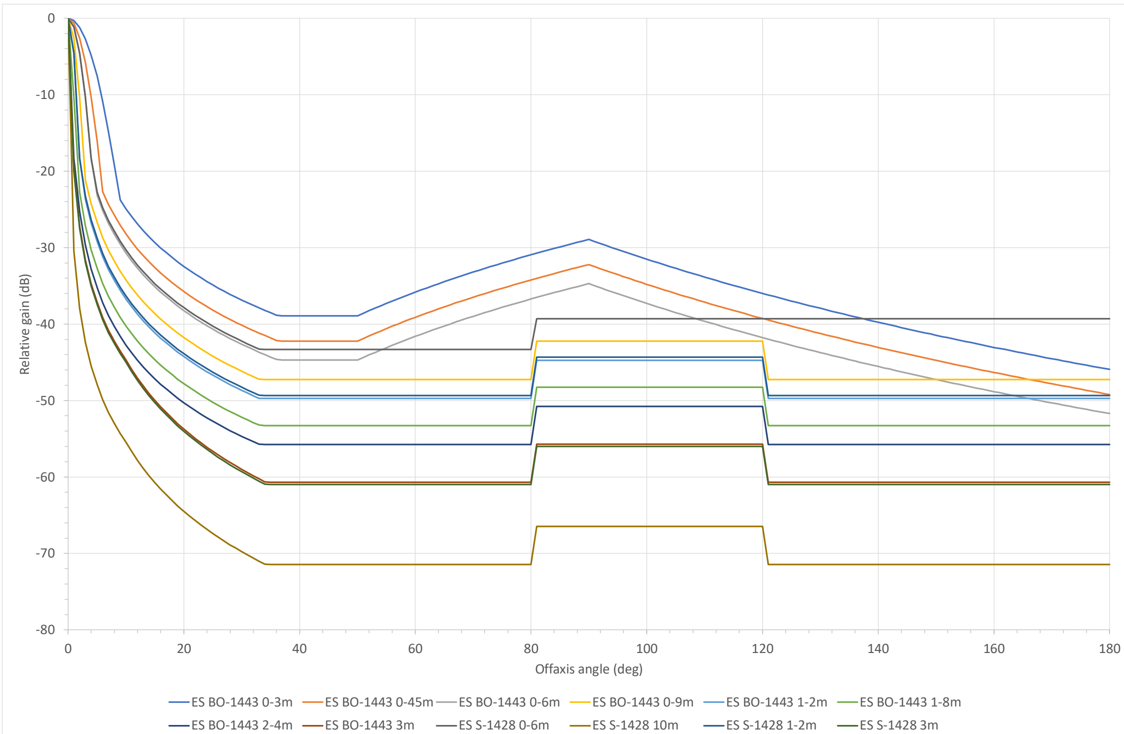


Figure 4: S.1428 and BO.1443 Gain Patterns

EPFD Analysis Structure

The ITU software, just like the TransFinite EPFD software, assumes that interference into a GSO satellite network can only be caused by those NGSO satellites that are inside the defined GSO exclusion zone (18° around the GSO arc for SpaceX's 3rd MOD), and where their beams are pointed away from the victim GSO ES so that they are emitting low power sidelobe power, plus the contribution of a user-specified number (Nco or nbr_op_sat) of satellites, in this case a single satellite outside the exclusion zone that is causing the highest EPFD.

In this case, since the value provided by SpaceX for Nco was one, there can only be a single source of NGSO satellite main beam interference into a GSO receive earth station sidelobe. All other sources of interference would be from the low sidelobes of the NGSO satellite into the GSO earth station main beam within the exclusion zone. This is illustrated in the Figures below.

Similarly, for the uplink EPFDup, the algorithm places a number of NGSO earth stations on a grid spaced by the average distance "avg_dist", but each location can only transmit, and thus contribute to EPFDup, if it communicates with satellite[s] outside the GSO exclusion zone. The number of links from each point on the grid to visible satellites depends on the user-specified parameter "nbr_sat_td", which SpaceX stipulated to be a single satellite. In practice, since SpaceX uses steerable beams, a single location, or two closely spaced earth stations, may be able to point to two satellites that are sufficiently far apart in the sky, and thus both collocated earth stations could contribute to EPFDup, and two different satellites could contribute to EPFDdn. Limiting these two parameters, nbr_sat_td and nbr_sat_co, to one would prevent SpaceX from providing more capacity in high demand areas by moving another co-frequency beam of an adjacent satellite to that same area.

We can confirm that SpaceX data assumes that only a single satellite can transmit to a given user location on a certain frequency assignment (channel) in the Ku-band at any given time. Similarly, a single earth station would transmit on a certain channel in the Ku-band from a given location to only one satellite, and co-frequency earth stations are assumed to be spaced at least 160km apart. These values are called nbr_op_sat (or Nco[latitude]) and nbr_sat_td (or ES_TRACK), respectively, in Recommendation ITU-R S.1503-2.

Our baseline study was to perform EPFD analysis for the data supplied by SpaceX for its 3rd FCC Mod filing, with a single co-frequency main beam interference source. We then assessed the impact of multiple co-frequency transmissions using Nco (and for the uplink nbr_sat_td) values of 2, 4 and 10 satellites. Even our maximum value of 10 is reasonable. If there are many users located in one geographical area, why would SpaceX not wish to have several satellites placing spot beams, even co-frequency spot beams on that area? This would provide much more persistent bandwidth that can otherwise be achieved with a single satellite beam, thereby increasing the data rate to each user and increasing the total number of users served. As demonstrated below, based on conservative assumptions, one beam would only be enough to provide reasonable service to perhaps 100 users actively requesting service at a busy hour, with 10 users fully using the resource (30 Mbps each) at any given point in time, even as demand from hundreds or thousands is likely at crowded venues.

Figure 5 below is a graphical representation of the various NGSO satellites near the GSO BSS earth station (45cm), based on the software's algorithm. The WCG algorithm for this situation placed the GSO satellite and its earth station at the coordinates depicted in the figure below.

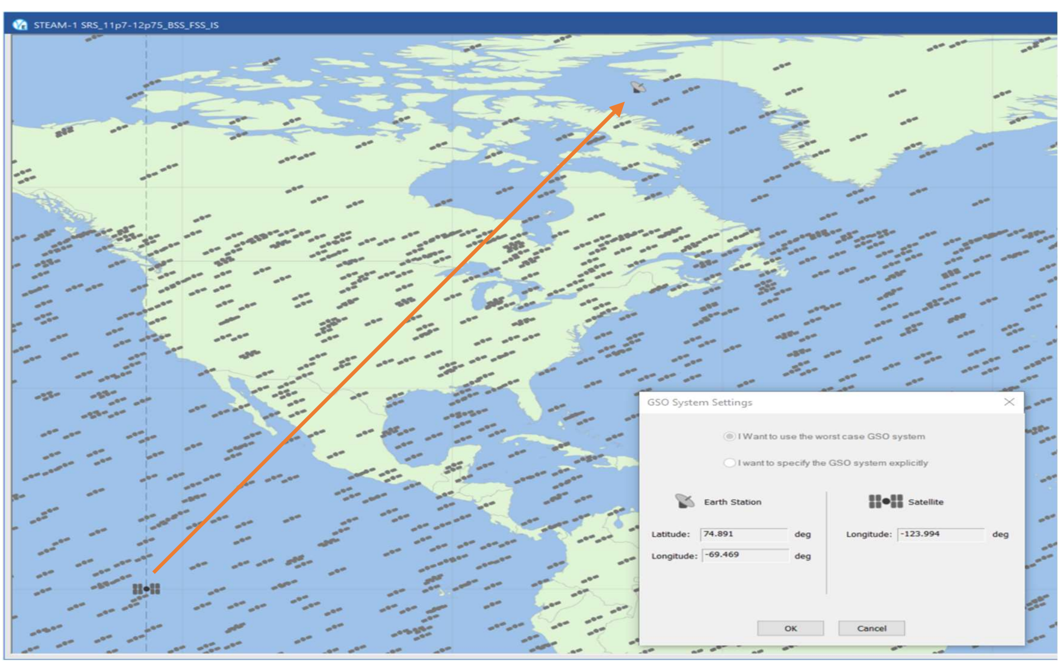


Figure 5: EPFDdn WCG Map for the 45cm BSS Terminal

Many of the SpaceX satellites depicted in the above figure will not be visible to the Earth station as they would be below the horizon. Also, some are in the GSO exclusion zone, so can only contribute to the EPFDdn from their antennas' far-sidelobes, resulting in low EPFD levels due to their low PFD levels (see Figure 1(a) for explanation). According to SpaceX's stated one-co-frequency-beam-at-a-time operational constraint, the key contributor to the EPFDdn is one (Nco = 1) NGSO satellite providing service near the GSO earth station and transmitting the maximum PFD directly on the receive earth station.

Figure 6 illustrates the point, where several contributors are depicted (there are more but their contributions were omitted for clarity), but only one at maximum PFD (Nco =1), cause a total EPFD at the receive earth station of -171.04 dBW/m^2 per 40-kHz, about the maximum expected for a single satellite that serves a given spot (refer to results section below).

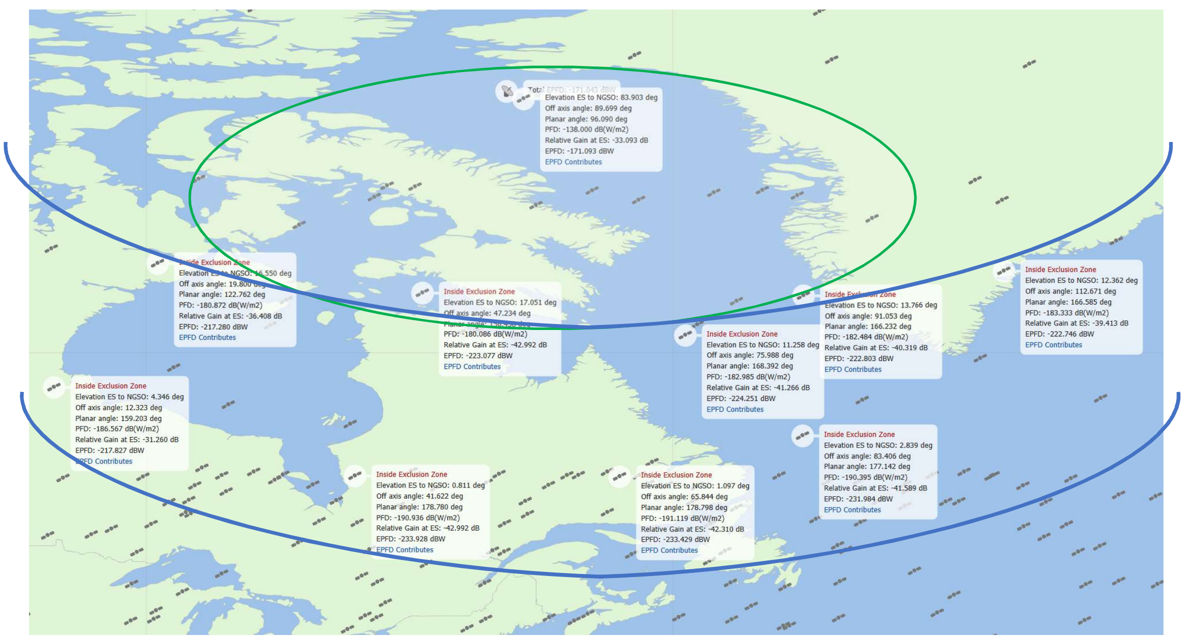


Figure 6: EPFDdn Calculations for the 45cm BSS Terminal – Nco =1

The above figure shows the small contributions to EPFD from several NGSO satellites located within the GSO exclusion zone (hand drawn in blue in the above picture). Also, several NGSO satellites are outside the GSO exclusion zone and above the 25° minimum elevation angle service area (green ellipse), so could be used to provide service in the area where the GSO earth station is located. However, SpaceX claims that this would never be the case. Further increasing the EPFD levels would be the PFD from all other beams originating from the multitude of satellites outside the exclusion zone, serving neighboring areas, which the S.1503-2 software ignores, unless Nco was set at a number that includes not only the co-coverage beams, but also takes into account these additional beams.

Since Nco was chosen to be a single satellite, only the worst possible interferer outside the GSO exclusion zone is assumed to contribute any EPFDdn towards the GSO receive earth station. This single NGSO satellite is responsible for 99% of the EPFDdn (-171.093 dB/m² per 40-kHz versus -171.043 dB/m² per 40-kHz in total).

If more than one SpaceX satellite were to put maximum, or close to maximum, PFD towards the GSO receive earth station, the results would be quite different. Figure 7 shows what contribution each NGSO satellite outside the GSO exclusion zone would cause to the overall EPFDdn with Nco = 10. In this figure, only the satellites outside the exclusion zone are shown for clarity, and some calculations are not displayed, as they otherwise would obstruct others.

So, Figure 6 above represents SpaceX's unrealistic operational scenario, where a single satellite beam can provide service to a spot and no other satellite outside the exclusion zone causes any EPFD, while Figure 7 represents a situation where multiple satellites could serve that same spot with co-frequency beams, while still not accounting for the beams from other visible satellites that may not be serving that exact same location.

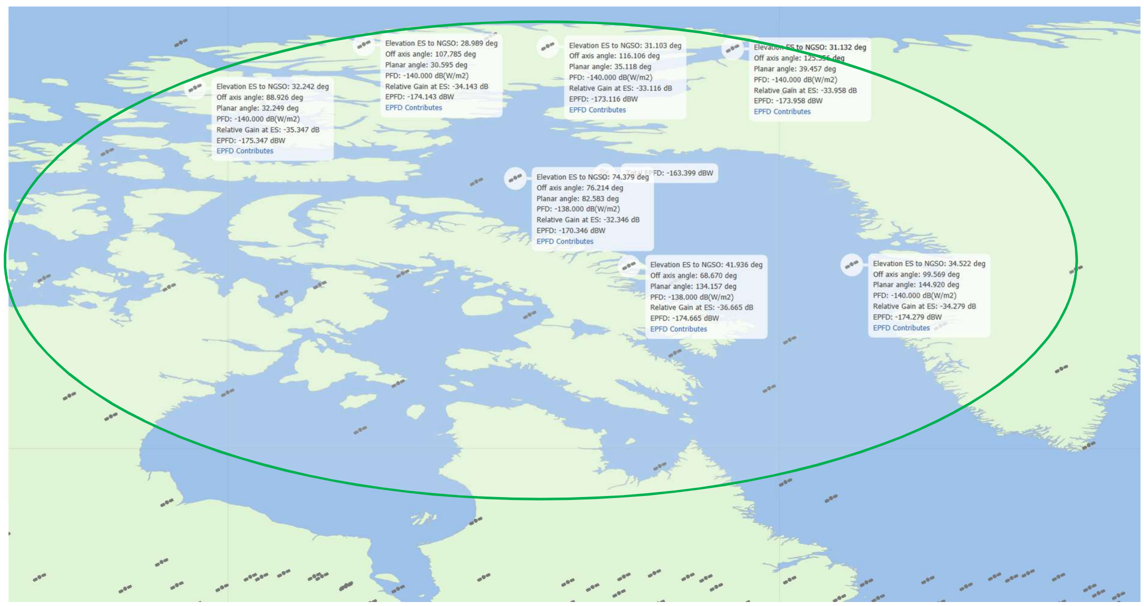


Figure 7: EPFDdn Calculations for the 45cm BSS Terminal if Nco >> 1

Noting that the green line is an approximation for the area in space where satellites are above the minimum 25° elevation angle for providing service, the total EPFDdn from multiple serving satellites would be much greater than the value corresponding to a single satellite. In the above figure, generated for Nco = 10, but where calculation results are displayed only for 7 of these NGSO satellites (three are too close to other satellites and their calculation box would overlap), it can be seen that the total EPFDdn to the GSO earth station is calculated as -163.40 dBW/m^2 per 40-kHz, an increase of 8 dB relative to the single satellite case. Considering the number of visible satellites and computing the statistical EPFD values, the EPFD limit is exceeded by up to 5.3 dB, as can be seen in Table 3 and Figure 14(e) in the following section. Whilst the value for Nco used was 10, there are many other satellites above the minimum elevation angle that could also contribute to the overall EPFD into the GSO BSS earth station. It really depends on where their beams are steered.

Even if all these NGSO satellites that are located above the 25 minimum elevation angle, which defines the service area, were not all causing the highest PFD at the victim GSO receive earth stations, their antenna beam gain rejection is finite, and so it can be expected that several of these satellites would have PFD values in excess of -150 dBW/m^2 per 40-kHz, so their contribution to the total EPFDdn would certainly not be negligible. Therefore, the assumption that Nco is equal to a single satellite by virtue of the fact that the S.1503-2 algorithm completely ignores the presence and interference contribution of other satellites leads to overly optimistic and unrealistic results. In fact, the EPFDdn will most certainly be higher than the values computed by the ITU software, which is limited by the user-defined value for Nco.

As DISH has already mentioned,[10] other NGSO operators have used Nco values that are significantly greater than one, up to 40, to make sure that the EPFD software properly captures the additional EPFD caused by the sidelobe performance of these other visible satellites that are outside the GSO exclusion zone and thus could be providing service over their respective, overlapping service areas. While SpaceX's use of steerable beams may warrant a lower Nco than that for systems using fixed beams, to avoid counting too many satellites with fully overlapping beams generating full PFD at the same spot, it certainly does not come close to justifying a value of one.

Assessing Reasonable Values of Nco

The difficulty in assessing a realistic value for Nco, unless one takes SpaceX's assertion of only 1 co-frequency beam from multiple satellites on a given location as being a maximum, is that SpaceX did not provide the number of Ku-band beams on each satellite, and the minimum angular spacing (or distance) between co-frequency beams from the same satellite, or adjacent satellites. It should provide that information so further analysis can be conducted.

Consider the map in Figure 8 below, where many SpaceX satellites are over the North America at any given point in time.

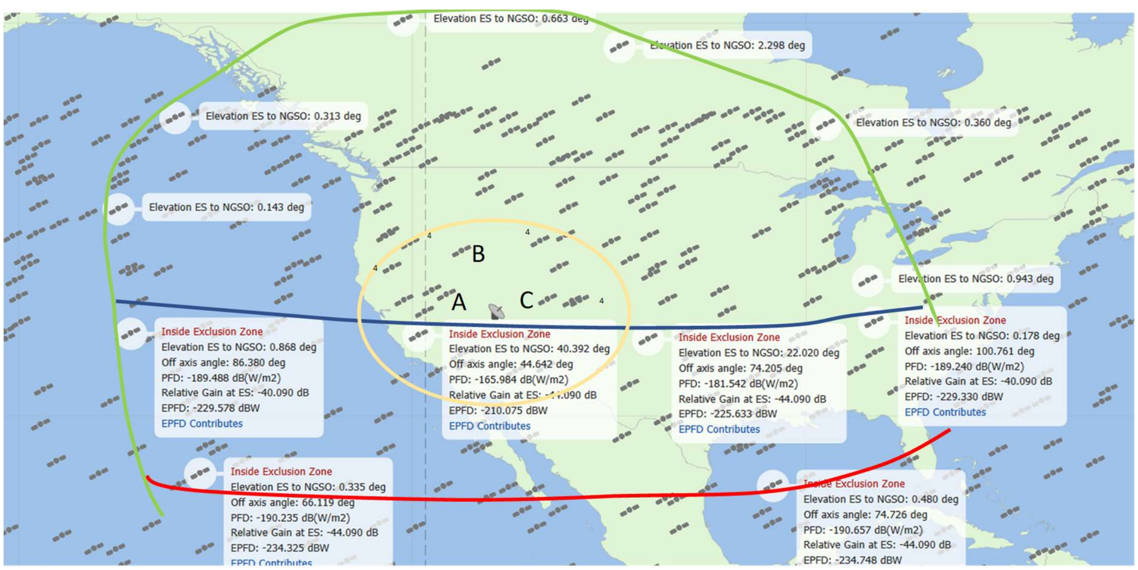


Figure 8: Layout of SpaceX Satellites over North America (Snapshot in Time)

[10] *See* DISH letters to Marlene Dortch, FCC, dated July 14, 2020 and August 6, 2020.

In this Figure, the green line represents the approximate area in space that is visible to the earth station depicted with the dish antenna, located in Beryl, Utah, a location chosen because it is rural and does not have many satellite directly overhead at that instant in time. The blue and red lines provide an indication of the SpaceX 18° GSO arc avoidance, so any satellites between these lines are in the exclusion zone, with very low PFD levels. There are 14 satellites that are outside the exclusion zone that are capable of serving Beryl with at least 25° elevation angle (the yellow ellipse), of which three were chosen, labelled as A, B and C, for the following Figure.

Let's further consider three of these satellites as per Figure 9 that could provide service to Beryl, which is an area that does not have many satellites overhead, thus representing a conservative case for Nco assessment. Consider further the three satellites are Northwest of the site (Satellite A located in a small cluster), Satellite B is almost due North, and the last one is Northeast (Satellite C again in a small cluster of satellites). These are just a few of the 14 satellites that could provide service in Beryl, at any given time, while maintaining the minimum 25° minimum elevation angle. Figure 9 shows what one beam from each of these three satellites would look like if steered towards Beryl.

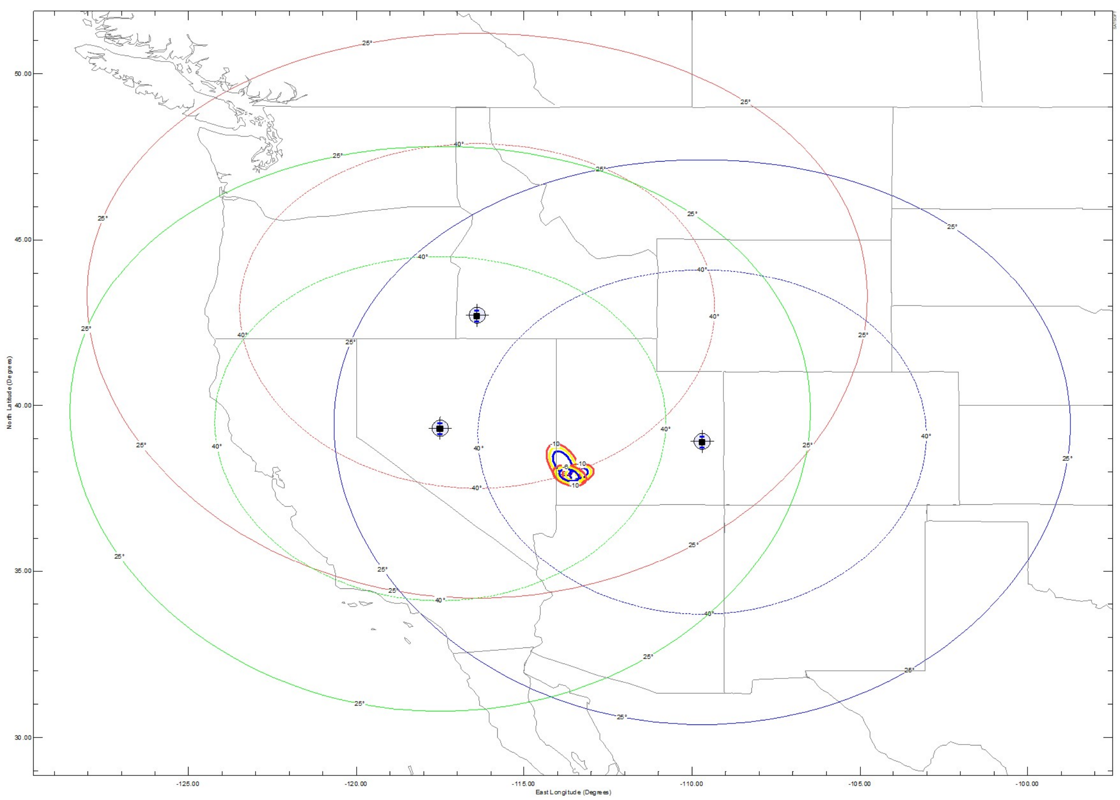


Figure 9: Layout of Three SpaceX Satellites that can provide service to Beryl (Snapshot in Time)

As can be seen from Figure 9, all three satellites have Beryl, Utah well within their 25° minimum elevation angle service area (outer ellipses); in fact Beryl would see all three satellites with over 40° elevation angles (smaller inside ellipses). While difficult to see, the SpaceX spot beams, corresponding to a satellite gain of 34.0 dBi,[11] from each of the three satellite positions are overlapping near Beryl.

Figure 10 below provides an expanded view of the area considered in this part of the analysis. The three small beams over Beryl are now more clearly visible[12] and one of these is located directly on the town while the other two beams are offset. The key question is "why would SpaceX knowingly avoid providing larger amounts of capacity if there were many users requesting service simultaneously in one area as depicted in this figure (or any other area in the USA for that matter)?"

In its FCC application, SpaceX states that such beams would never overlap. The ITU Radio Regulations are silent as to the validation of Nco, relying on the operator (and its filing administration) to adhere to conditions that they have specified in their filings. Because SpaceX filed Nco equal to one, the ITU supposes that this will be the case.

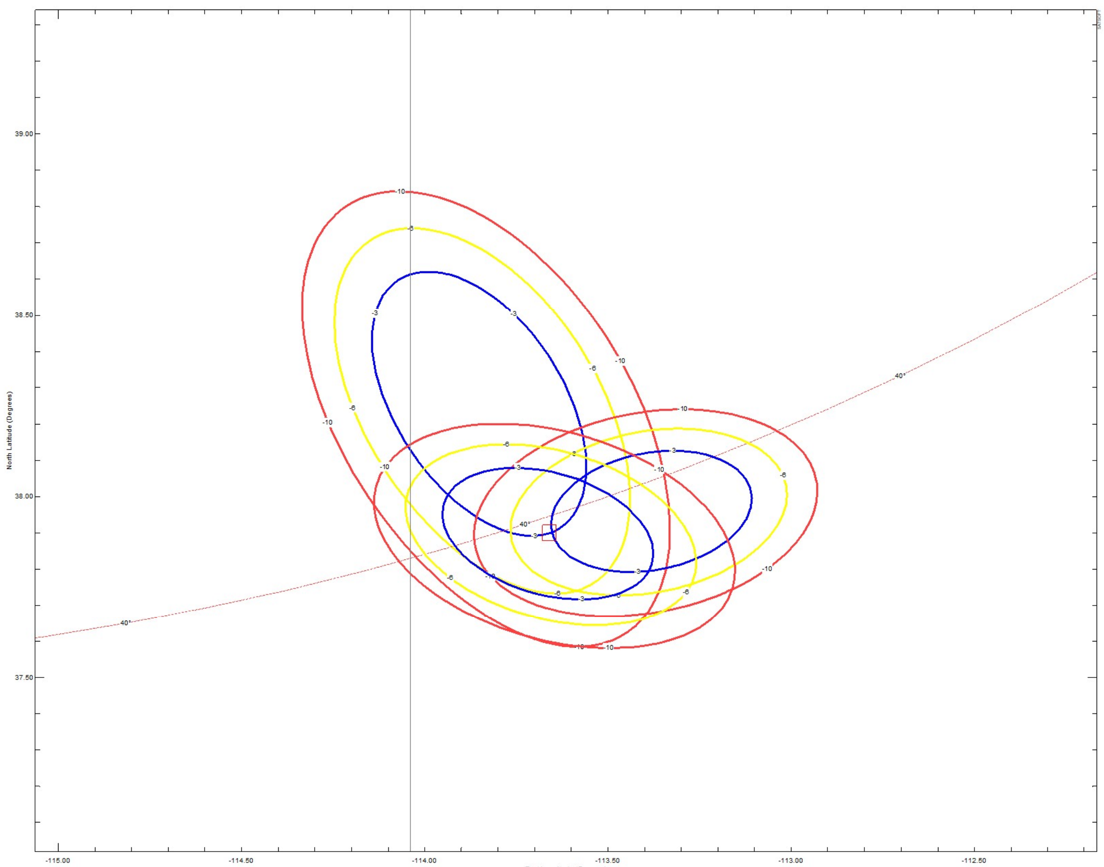


Figure 10: Expanded Layout of Three SpaceX Satellites over Sardinia (snapshot in time)

In Figure 10, the main source of EPFD would be the beam located directly on Beryl (represented as the orange square in the middle of the figure), whereas the other two beams are assumed to be 3 dB

[11] According to the Schedule S data provided by SpaceX for the lowered altitude satellites, the satellite transmit gain is 34 dBi.

[12] In this figure, the beam contours are -3 dB (blue), -6 dB (yellow) and -10 dB (red).

lower PFD relative to their peak value. Nevertheless, by choosing Nco equal to one, the software will only model the one over Beryl and ignore the impact of the other two beams. In reality, these other two beams would aggregate such that their combined EPFD would likely be equal to the highest EPFD beam, thus resulting in an Nco-equivalent value of 2 satellites. If Beryl, or any other location considered, warranted sufficient traffic so as to have two or more beams completely overlapping, the calculated EPFD values would be at least 3 dB below the actual EPFD levels.

It is our opinion that the value of Nco should be between 2 and 4, if a single satellite serves a given area, to account from sidelobe PFD from co-frequency beams of adjacent satellites, unless such beams are always separated by large distances, such that their off-axis gain is well below (-20 dB) the main gain corresponding to peak PFD. A value for Nco between 4 and 10 would be reasonable, if SpaceX allows two or more satellites to place beams with peak PFD on the same spot on Earth, again to account for these two or more main beams plus the sidelobes of all other satellite beams that would be at some distance away from the victim GSO earth station. In fact, if there are no real restrictions on the number of co-frequency satellites that can serve an area, even if their beams do not completely overlap, the effective value for Nco could be much greater than 10, the maximum studied for this report.

Moreover, the Nco may not fully capture the satellites contributing to the EPFD level at a receive BSS or FSS dish, if it is exactly representing the maximum of co-frequency, co-coverage beams. Figure 11 illustrates that multiple co-frequency beams can aggregate EPFD into a given GSO earth station, even if these beams are maintained with separation on the ground. As illustrated, if each satellite carried eight beams, each with a single 240 MHz carrier, the sidelobes from the beams serving areas other than the victim GSO earth station location, in this case Beryl, would still contribute to the overall EPFD.

The figure below takes that same time step and satellite configuration as per Figure 8 above, and shows the fourteen visible satellites and places one beam for each satellite, which is deemed to be co-frequency with the other depicted beams. The location of the satellite beams, aside from the one covering Beryl, was chosen to represent possible locations that each of these satellites may need to cover at some point in time. Note that the figure illustrates only the fourteen satellites that are above the minimum 25° elevation angle; however, in reality, there could also be aggregation of energy from all satellites visible from that location, even those below that minimum operational elevation angle. Considering Figure 8, there could easily be over 100 SpaceX satellites above the horizon at that location. All of these satellites will have some finite PFD towards the victim GSO earth station, no matter where their beams are pointed, and they will further contribute to the overall EPFD beyond the levels computed by the ITU software.

SpaceX claims that there would not be two co-frequency beams from different satellites serving the same spot, however, the size of the "spot" is not defined. In the figure below, we have centered one of the beams on Beryl, as per the previous figure, assumed two more beams are located nearby, so that their -6 dB contours cover that location, four would result in -10 dB to -20 dB contours reaching the town, and the rest of the satellites would have beams located sufficiently far away to ensure that there would be at least 20 dB gain discrimination. While this is illustrative only, the point is that there will always be PFD aggregating towards a GSO receive earth station. Therefore, assuming Nco equals one is ignoring the EPFD contribution of all these other satellites, not to mention the hundred or so satellites outside the serving area, i.e., where the elevation angle is less than 25 degrees.

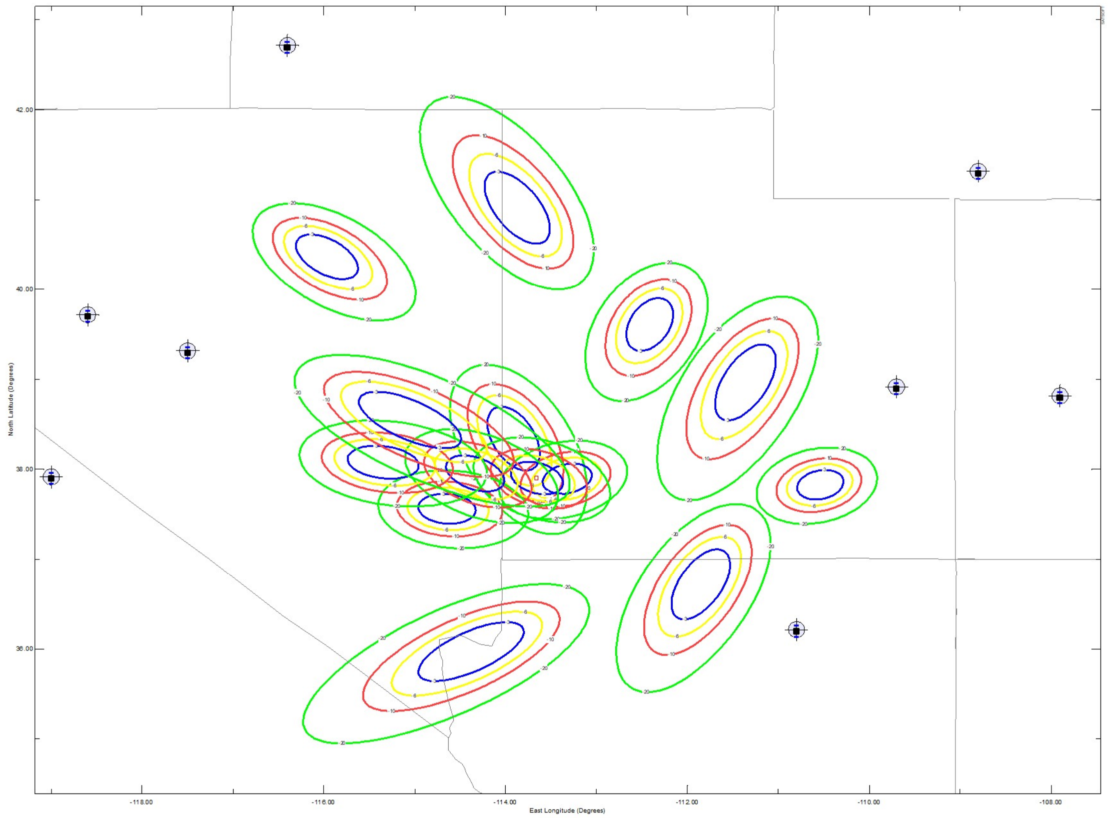


Figure 11: Possible Co-frequency Beam Coverage from 14 SpaceX Satellites (Snapshot in Time)

Capacity Impact with Different Values of Nco

To further illustrate the point about Nco being more than one in reality, we can consider the capacity implications of such a decision versus an increase in Nco. Let's assume that each SpaceX Starlink satellite has multiple beams, each carrying one channel with a 240 MHz carrier bandwidth.[13] Depending on the link budget, this could support about 200 to 300 Mbps of user traffic per beam. If an area requires more capacity, in terms of bit rate, than what can be achieved by one beam, it would require either another beam from that same satellite (using a different channel) or else other beams from other adjacent satellites. The satellite that is currently serving the users in a particular location needs to also cover a fairly wide geographic area as depicted in Figures 9 and 10. If that were not the case, it would be impossible to explain SpaceX's decision to lower the minimum operational elevation angle to 25° from its original 40° value. If each satellite were to only cover a very small geographical footprint, the user terminal design would have been greatly simplified by maintaining a higher minimum angle.

[13] This level of detail is not provided by SpaceX in its FCC application, which does not describe the channelization and beam structure, does not provide any indication of the number of Ku-band user beams on each satellite, nor their spacing; but the Schedule S stipulates emission designators that have 240 MHz bandwidth. We believe obtaining such information is important and warrants further analysis.

This one beam would thus likely support no more than 10 users actively requesting service in one area at a busy hour, providing 30 Mbps peak data rate to each (10 users times 30 Mbps equals 300 Mbps). But in reality, there are probably 50 to 100 users that are sharing that same 300 Mbps data pipe, using time-division multiplex. If the area being served, rural Utah in our earlier example, is a large remote village, or a busy port without terrestrial infrastructure, or public transportation, the number of users seeking simultaneous access, especially during early evening busy hours, could easily be counted in the thousands. SpaceX would have the technical ability, and would likely not refuse, to serve these users, without sacrificing quality of service, by simply overlapping another beam from another satellite. In fact, the demand may require the addition of many such beams, and there will be a high likelihood that several of these additional beams would be co-frequency to the original serving beam, thus Nco would no longer be constrained to one, but could be much higher. A remote town with no terrestrial infrastructure but with thousands of inhabitants, would likely require much more capacity that can be delivered with one or even a few SpaceX beams. This would justify the use of multiple co-frequency satellites to provide service to such concentrations of population, and thus SpaceX's assertion that Nco = 1 becomes unrealistic.

SpaceX EPFD Results

The results of these runs are shown in the three tables below. These include the results provided by SpaceX to the FCC for its 3rd MOD filing, our baseline analysis with Nco = 1, as well as results for Nco equal to 2, 4 and 10. Table 2 shows the status of each run, in terms of PASS/FAIL, noting that any EPFD level in excess of the limit for any percentage of time, no matter how small, would result in a FAIL status.

Run/Status:	SpaceX	Baseline	Nco = 2	Nco = 4	Nco =10
EFPDup	PASS	PASS	FAIL	FAIL	FAIL
EPFDdn FSS 0.6m	PASS	PASS	FAIL	FAIL	FAIL
EPFDdn FSS 1.2m	PASS	PASS	FAIL	FAIL	FAIL
EPFDdn FSS 3m	PASS	PASS	PASS	FAIL	FAIL
EPFDdn FSS 10m	PASS	PASS	PASS	PASS	PASS
EPFDdn BSS 0.3m	PASS	PASS	PASS	PASS	FAIL
EPFDdn BSS 0.45m	PASS	PASS	FAIL	FAIL	FAIL
EPFDdn BSS 0.6m	PASS	PASS	FAIL	FAIL	FAIL
EPFDdn BSS 0.9m	PASS	PASS	PASS	FAIL	FAIL
EPFDdn BSS 1.2m	PASS	PASS	FAIL	FAIL	FAIL
EPFDdn BSS 1.8m	PASS	PASS	PASS	FAIL	FAIL
EPFDdn BSS 2.4m	PASS	PASS	PASS	FAIL	FAIL
EPFDdn BSS 3m	PASS	PASS	PASS	PASS	FAIL
EPFDis	PASS	PASS	PASS	PASS	PASS

Table 2: Summary of Results

Table 3 provides the margin (positive values) or excess EPFD (negative values) by looking only at the maximum EPFD value from the Cumulative Distribution Function (CDF). This is normally an indicator of whether the EPFD value will exceed the EPFD limits during the instantaneous in-line event, i.e., when the most interfering NGSO satellite is directly between the GSO satellite and its receive earth station.

MaxEPFD	SpaceX	Baseline	Nco =2	Nco =4	Nco =10
Up	0.3	0.2	-2.2	-4.6	-8.0
Dn FSS 0.6	9.3	9.5	9.0	7.9	6.5
Dn FSS 1.2	8.7	7.9	7.7	6.8	7.2
Dn FSS 3.0	9.7	8.0	8.3	8.0	8.0
Dn FSS 10.0	9.7	8.2	8.2	8.0	8.0
Dn BSS 0.3	9.0	9.0	6.0	3.7	2.2
Dn BSS 0.45	10.8	10.8	8.0	5.6	4.0
Dn BSS 0.6	6.2	6.0	5.7	5.5	5.0
Dn BSS 0.9	7.0	6.5	7.2	6.3	6.0
Dn BSS 1.2	7.5	7.0	7.7	6.8	6.5
Dn BSS 1.8	8.0	8.0	7.9	7.5	7.5
Dn BSS 2.4	8.0	8.0	8.0	8.0	8.0
Dn BSS 3.0	8.0	8.0	8.2	8.0	8.0
IS	0.5	0.5	0.5	0.5	0.5

Table 3: PFD Runs – Max EPFD Results

Table 4 similarly shows the margin (positive values) or excess EPFD (negative values) for the EPFD value corresponding to 10% of the time. This is a useful metric as this is the time percentage that roughly corresponds to a long-term event, i.e., the EPFD levels exceeded for more than 10% of time may cause link margin reduction in the GSO link and can be used to estimate the link availability reduction due to NGSO interference. In Table 4, all cells that are highlighted in orange correspond to an excess EPFD, i.e., EPFD limit in the ITU Radio Regulations minus the computed EPFD, hence the negative values.

EPFD (10%)	SpaceX	Baseline	Nco =2	Nco =4	Nco =10
Up	0.5	0.35	-2.1	-4.5	-8.0
Dn FSS 0.6	1.0	1.0	-0.5	-2.7	-5.3
Dn FSS 1.2	1.2	1.4	-0.3	-2.0	-4.7
Dn FSS 3.0	2.5	2.6	1.5	-0.1	-2.5
Dn FSS 10.0	7.0	7.0	5.8	2.5	2.0
Dn BSS 0.3	4.0	4.0	2.0	0.2	-1.8
Dn BSS 0.45	1.0	1.0	-1.0	-2.8	-4.8
Dn BSS 0.6	1.5	1.5	-0.4	-2.2	-4.5
Dn BSS 0.9	2.1	2.2	1.2	-1.3	-3.8
Dn BSS 1.2	1.3	1.3	-0.1	-2.0	-4.5
Dn BSS 1.8	2.8	2.8	1.2	-0.7	-3.3
Dn BSS 2.4	3.0	3.0	1.6	-0.4	-2.8
Dn BSS 3.0	4.0	4.0	2.5	1.0	-1.3
IS	2.3	2.3	2.3	2.3	2.3

Table 4: PFD Runs – 10% of time EPFD Results

EPFDup (14-14.5 GHz)

The SpaceX data contained in the SRS data files assumes that, at any location, only a single user terminal can transmit to a satellite operating in Ku-band at any given time. Co-frequency earth stations are assumed to be spaced at least 160km apart. This parameter is called nbr_sat_td (or ES_TRACK) in Recommendation ITU-R S.1503-2.

Figures 12 (a and b) show the results for EPFDup, with 12a provided by SpaceX in its 3rd MOD satellite filing to the FCC and 12b for our baseline case using the data from SpaceX 3rd FCC mod. There is less than 1dB margin below the EPFDup limit, even with a single satellite receiving from each point on the ground.

Figures 12c to 12e show the EPFD curves for 2, 4 and 10 simultaneous transmissions from a single location on Earth to as many satellites. The EPFDup limit, which is a single value not to be exceeded for any percentage of time, is exceeded by 2.2 dB, 4.6 dB and 8 dB for these three scenarios.

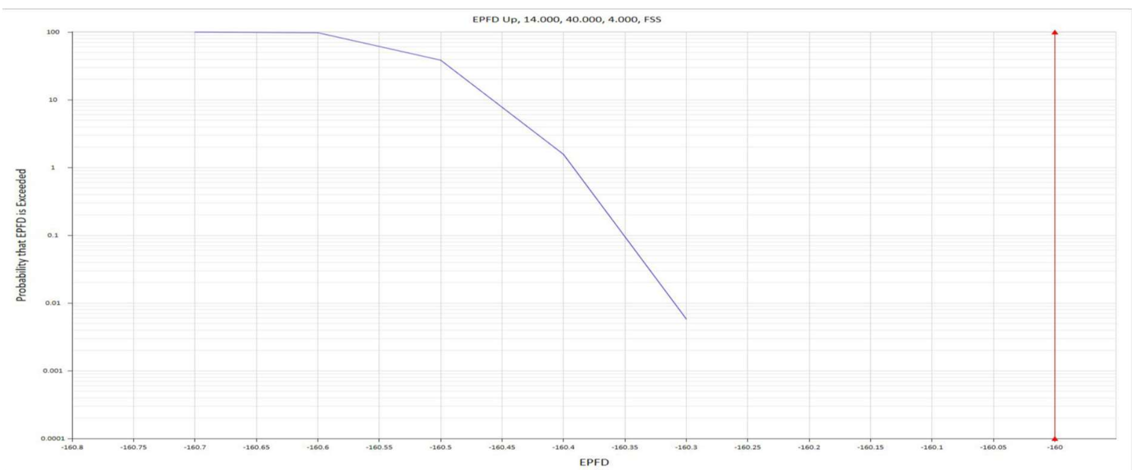
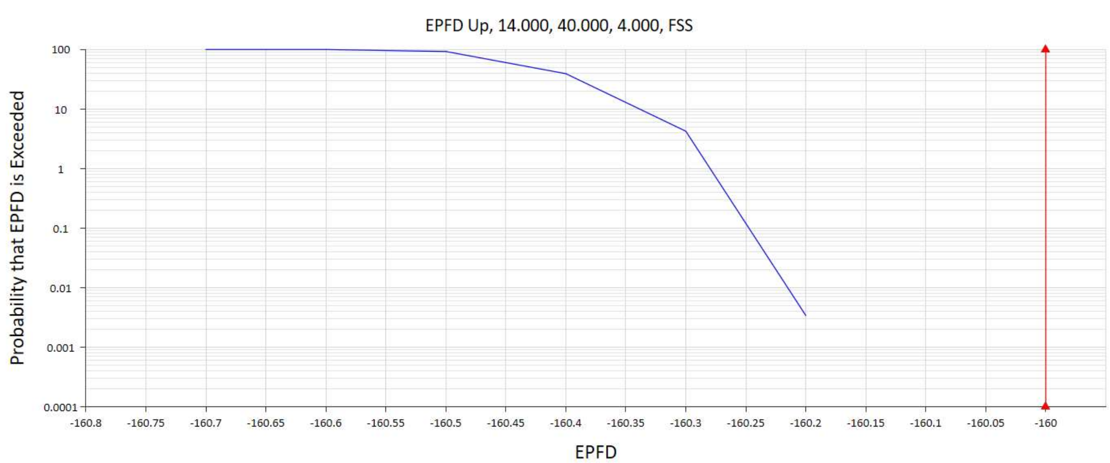
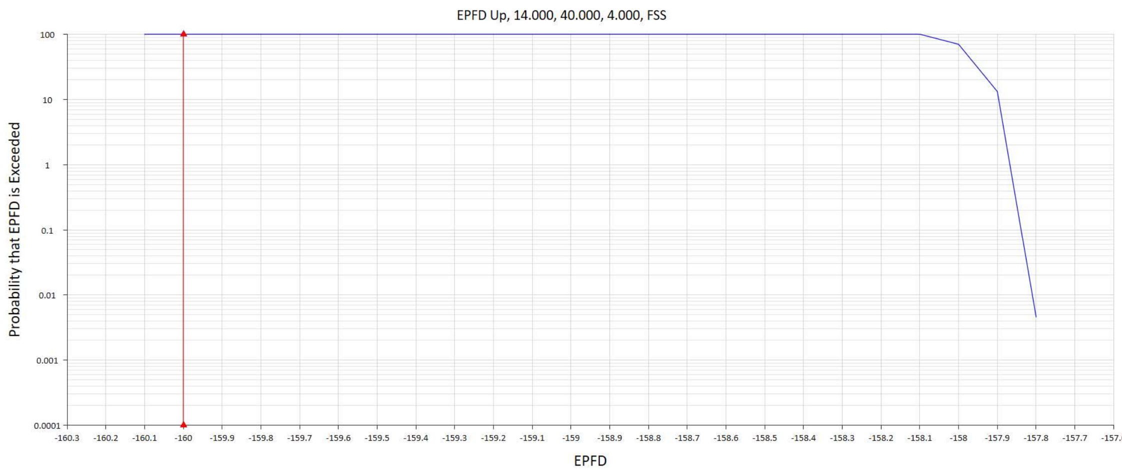


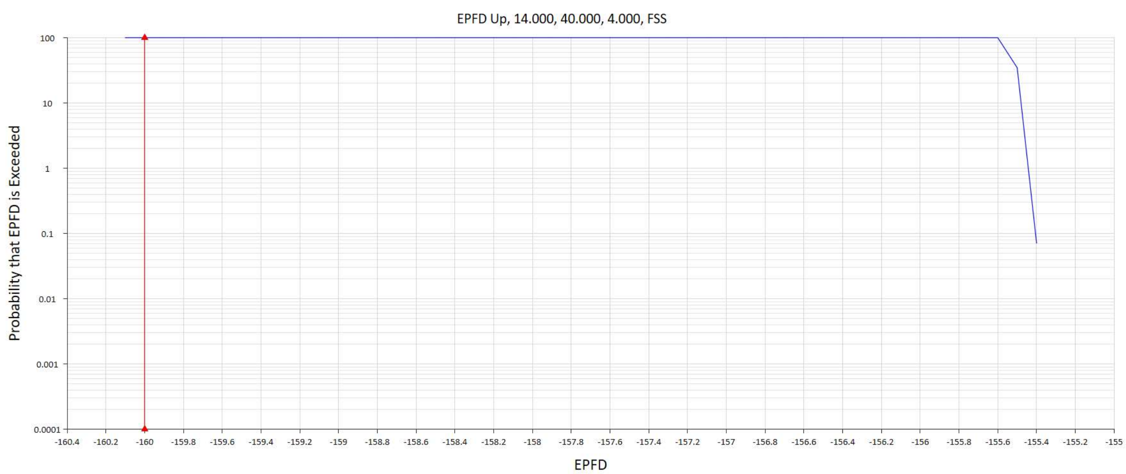
Figure 12a: SpaceX EPFDup Run



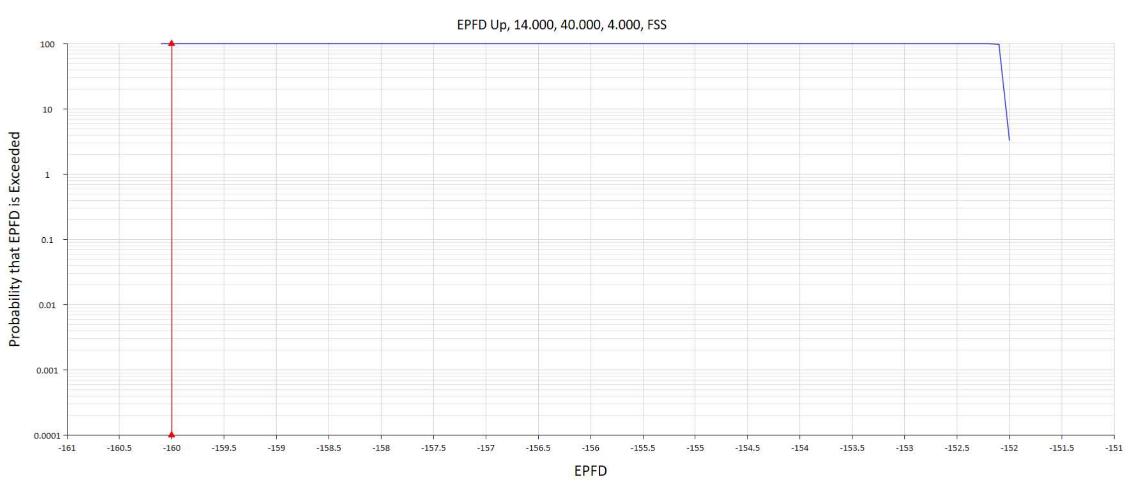
b: Baseline EPFDup Run nbr_sat_td = 1



c: EPFDup Run nbr_sat_td = 2



d: EPFDup Run nbr_sat_td = 4



e: EPFDup Run nbr_sat_td = 10

EPFDdn BSS (11.7-12.75 GHz)

$\mathbf{EPFD_{DN}}$ in 12.2-12.7 GHz (BSS in Region 2) which applies as well in 11.7-12.2 GHz band (BSS in Regions 1 and 3)

The first result in each of the Figures below, called Figure x(a), reproduces the EPFDdn curves provided by SpaceX in its 3rd MOD application to the FCC. These runs assume the WCG since the BR software does not allow user-specified satellite orbital position and earth station location. We are aware that, for complex systems with multiple orbits, the WCG algorithm contained in Rec. ITU-R S.1503-2 may not yield the worst EPFD results. However, at this stage, we did not attempt to find the worst geometry for this constellation.

The results for EPFDdn into BSS earth stations are contained in Figures 13 through 20, as indicated in the Table below.

EPFD	SpaceX	Baseline	Nco =2	Nco =4	Nco =10
Dn BSS 0.3	Fig 13a	Fig 13b	Fig 13c	Fig 13d	Fig 13e
Dn BSS 0.45	Fig 14a	Fig 14b	Fig 14c	Fig 14d	Fig 14e
Dn BSS 0.6	Fig 15a	Fig 15b	Fig 15c	Fig 15d	Fig 15e
Dn BSS 0.9	Fig 16a	Fig 16b	Fig 16c	Fig 16d	Fig 16e
Dn BSS 1.2	Fig 17a	Fig 17b	Fig 17c	Fig 17d	Fig 17e
Dn BSS 1.8	Fig 18a	Fig 18b	Fig 18c	Fig 18d	Fig 18e
Dn BSS 2.4	Fig 19a	Fig 19b	Fig 19c	Fig 19d	Fig 19e
Dn BSS 3.0	Fig 20a	Fig 20b	Fig 20c	Fig 20d	Fig 20e

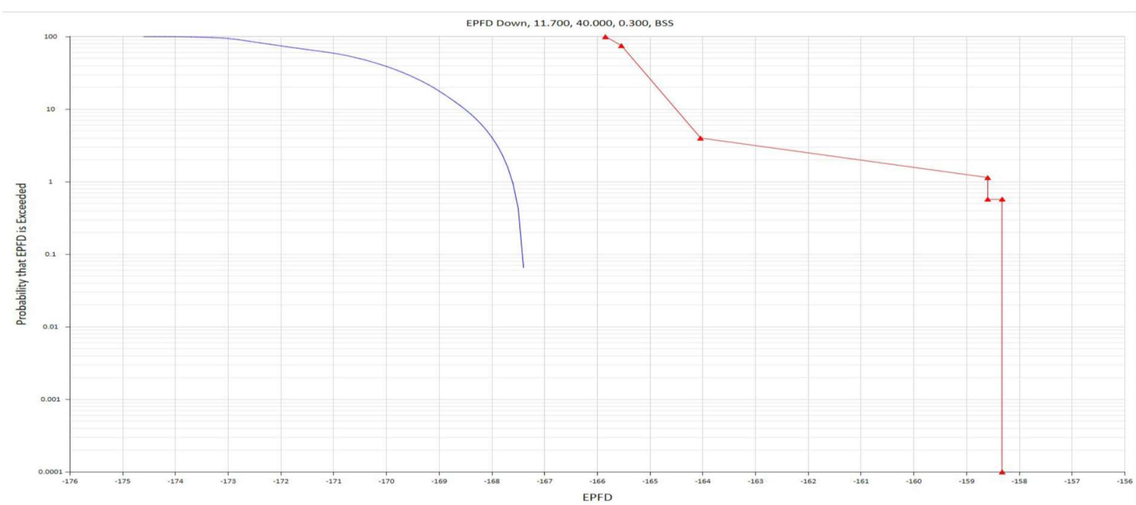
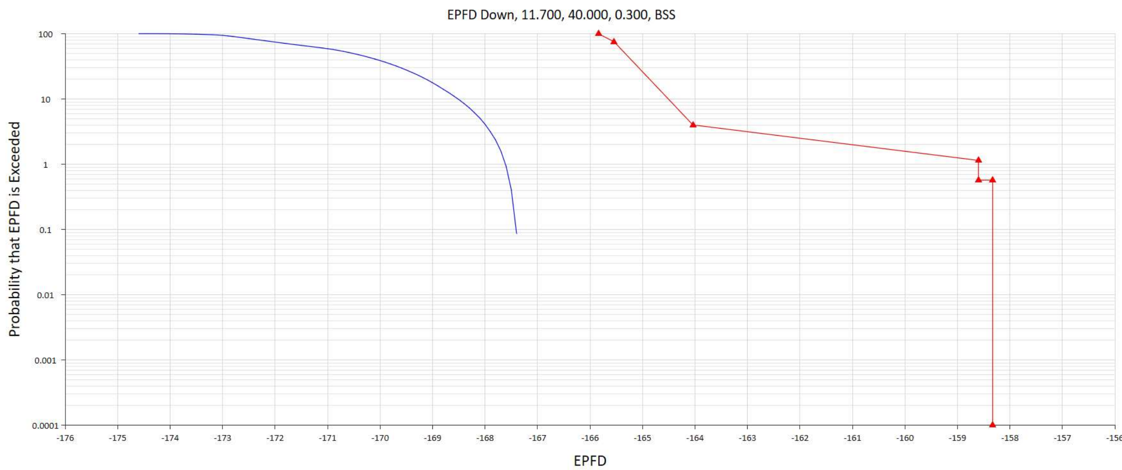
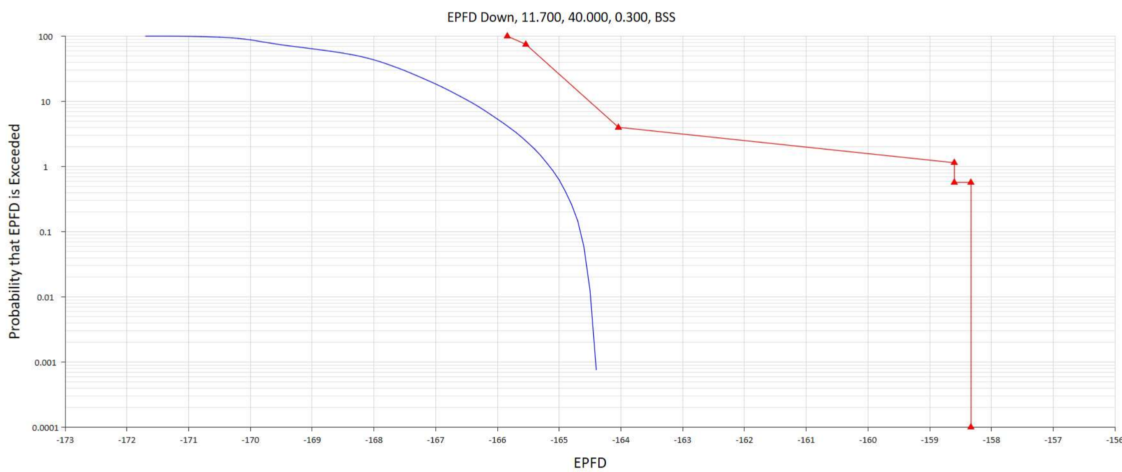


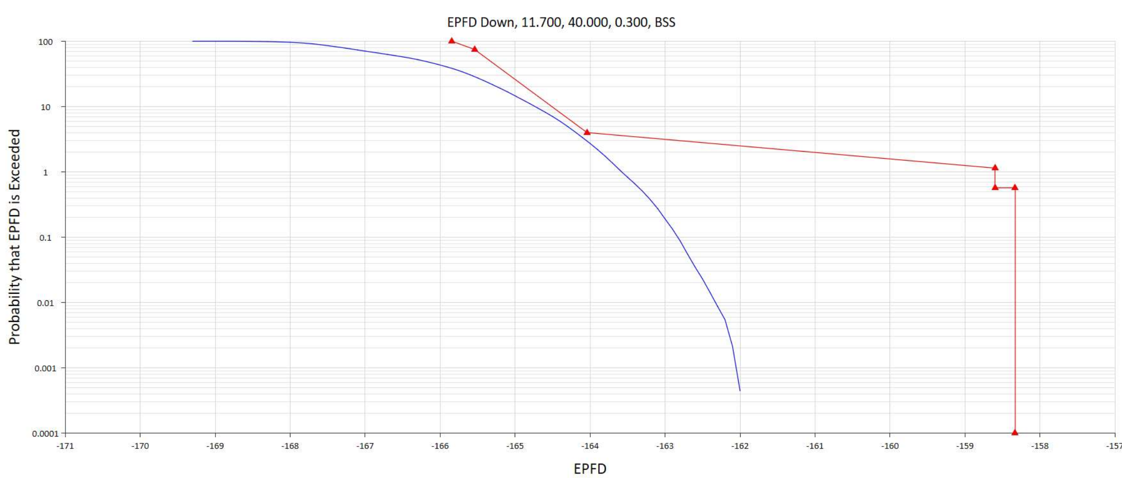
Figure 13a: SpaceX EPFDdn Run – BSS 30 cm antenna



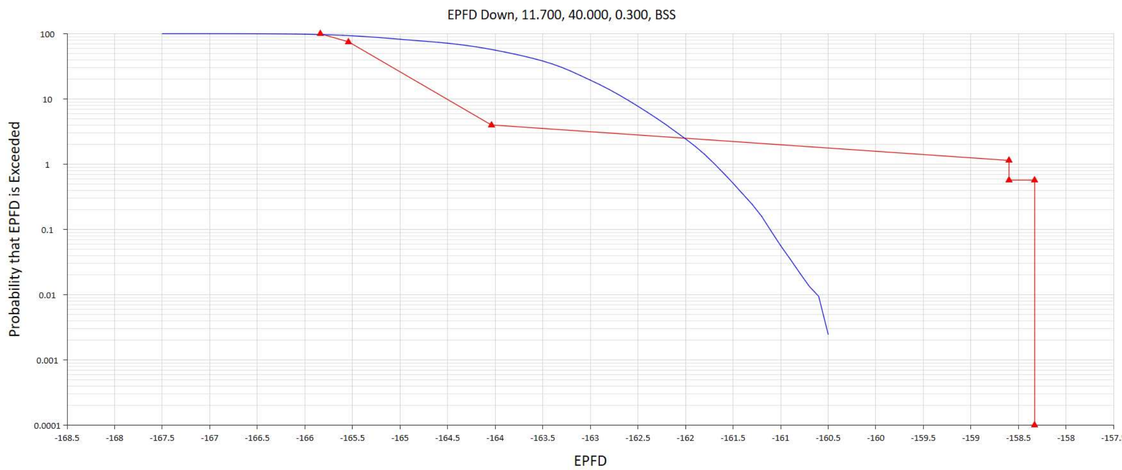
b: Baseline EPFDdn Run – BSS 30 cm antenna



c: Nco = 2 EPFDdn Run – BSS 30 cm antenna



d: Nco = 4 EPFDdn Run – BSS 30 cm antenna



e: Nco = 10 EPFDdn Run – BSS 30 cm antenna

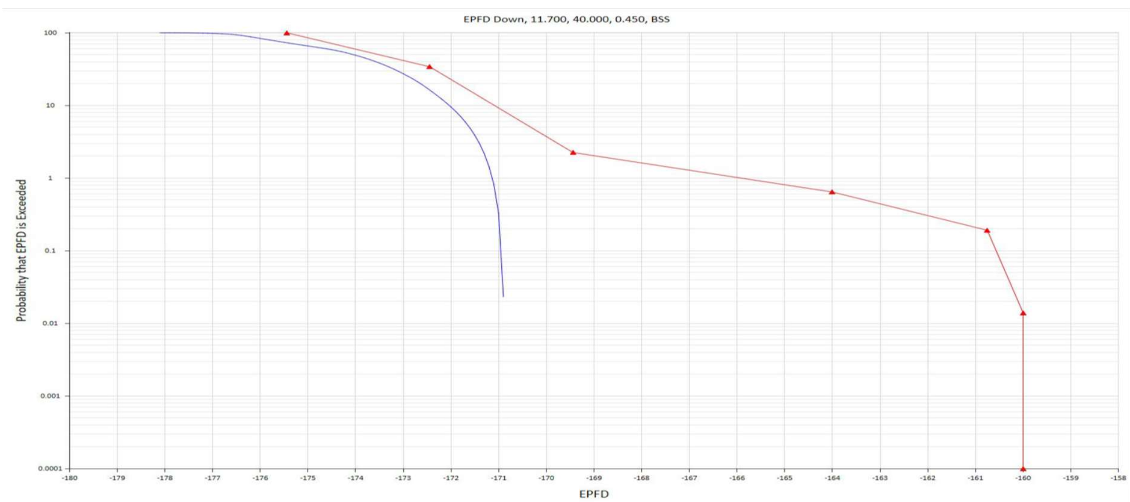
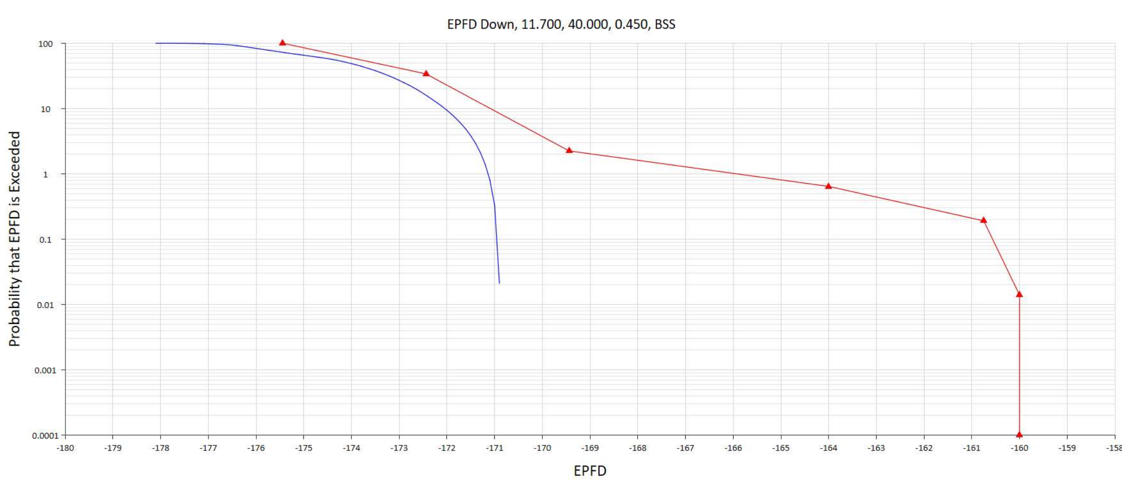
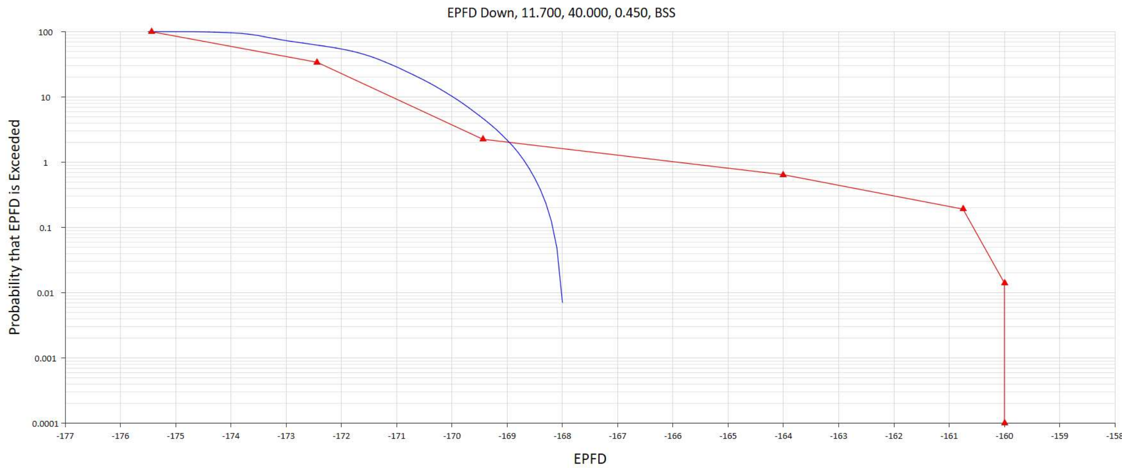


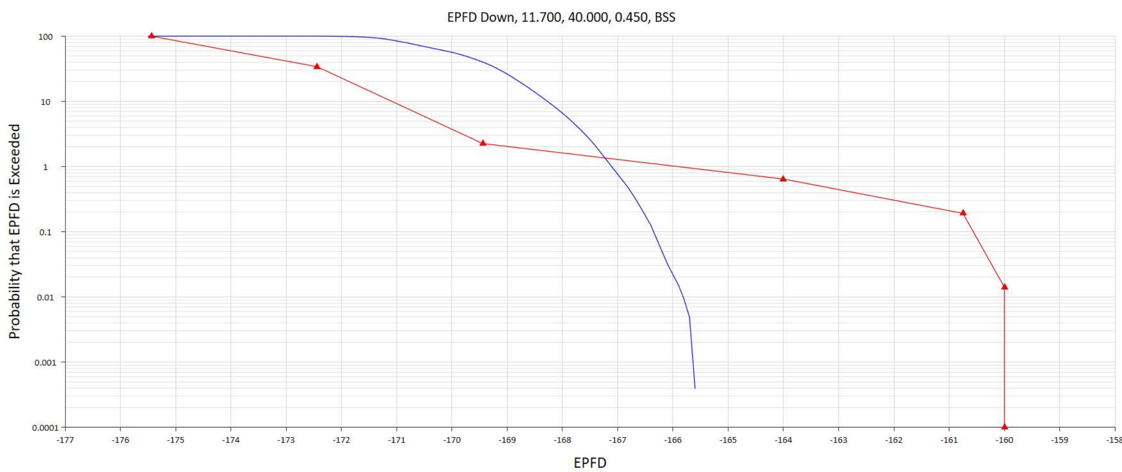
Figure 14a: SpaceX EPFDdn Run – BSS 45cm antenna



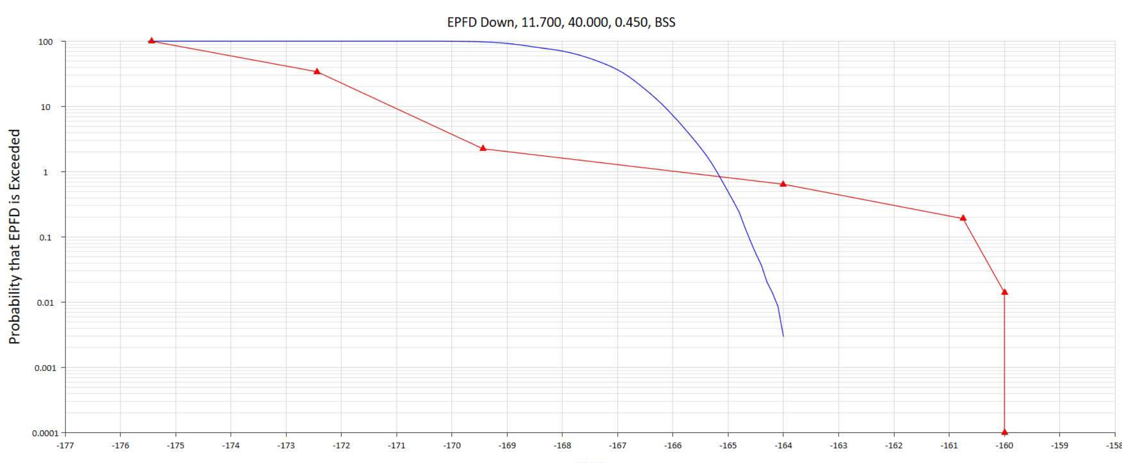
b: Baseline EPFDdn Run – BSS 45cm antenna



c: Nco = 2 EPFDdn Run – BSS 45cm antenna



d: Nco = 4 EPFDdn Run – BSS 45cm antenna



e: Nco = 10 EPFDdn Run – BSS 45cm antenna

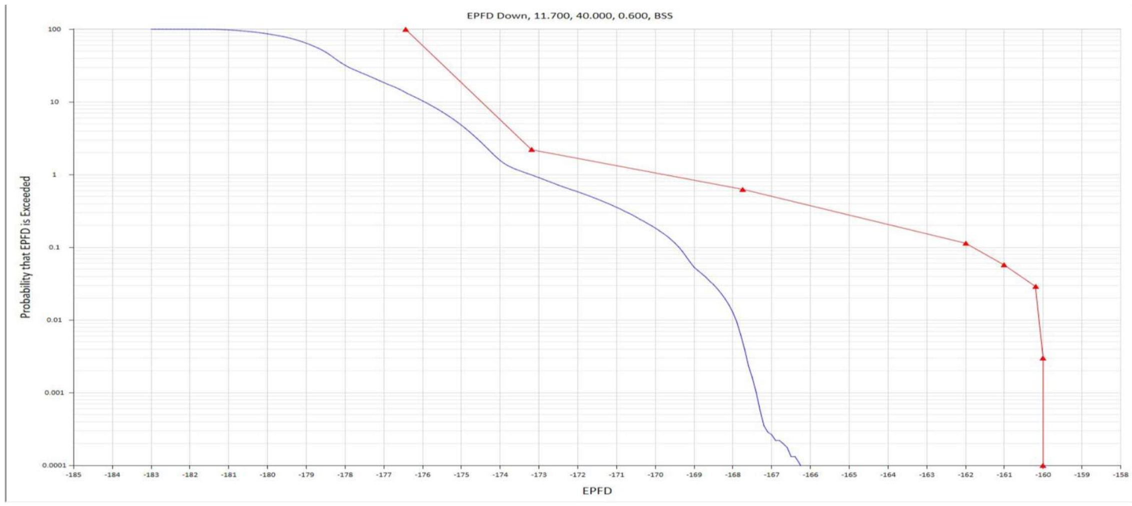
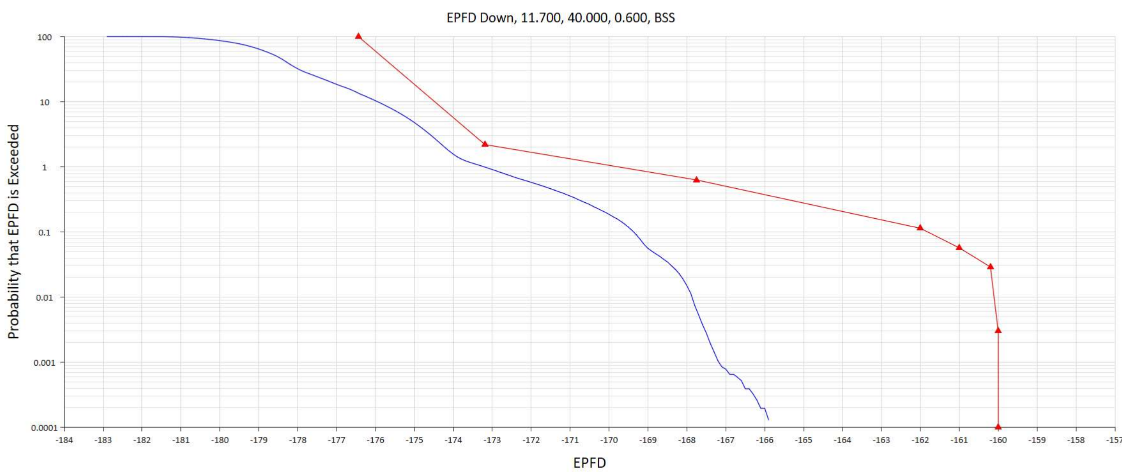
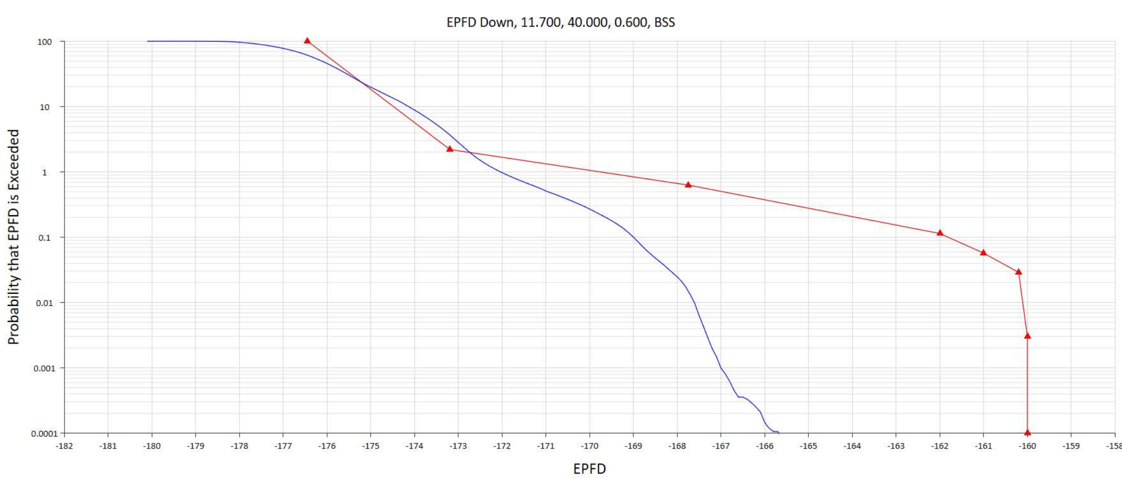


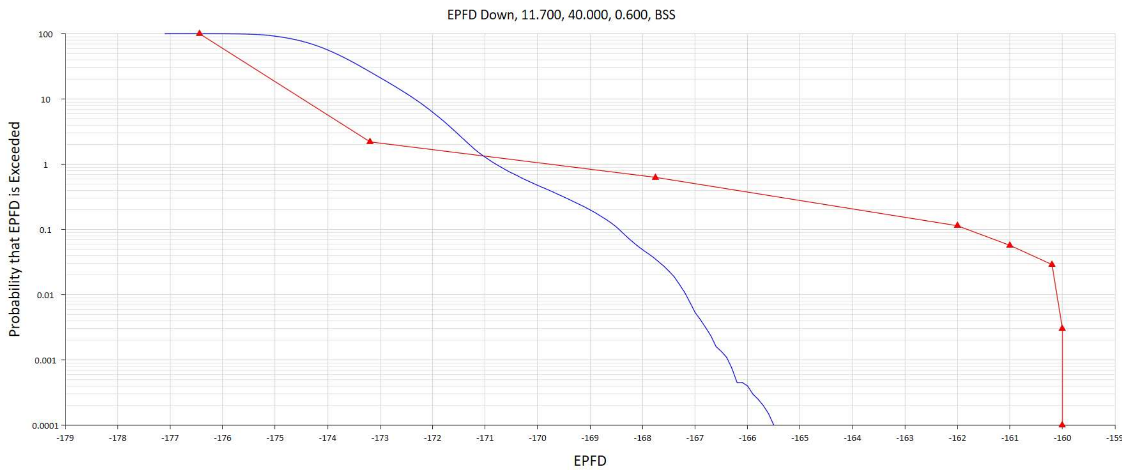
Figure 15a: SpaceX EPFDdn Run – BSS 60 cm antenna



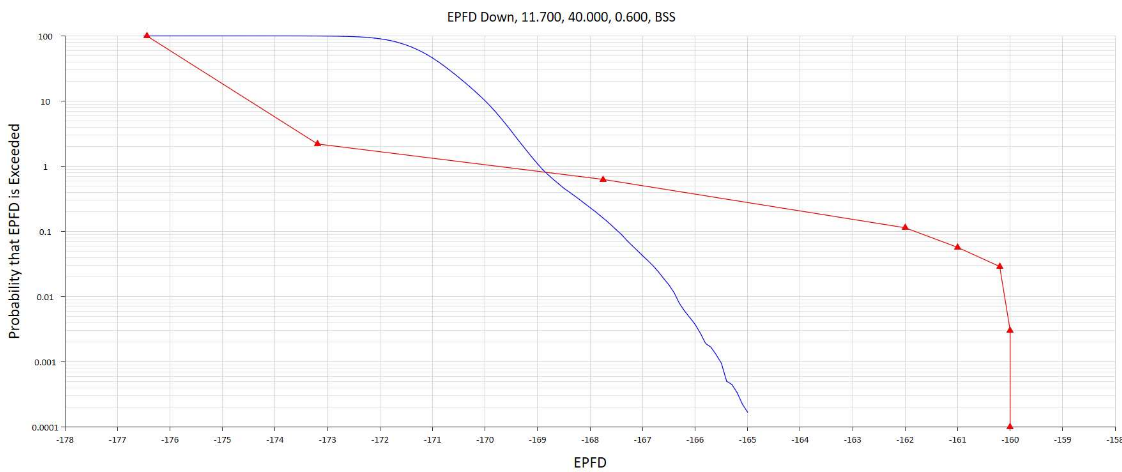
b: Baseline EPFDdn Run – BSS 60 cm antenna



c: Nco = 2 EPFDdn Run – BSS 60 cm antenna



d: Nco = 4 EPFDdn Run – BSS 60 cm antenna



e: Nco = 10 EPFDdn Run – BSS 60 cm antenna

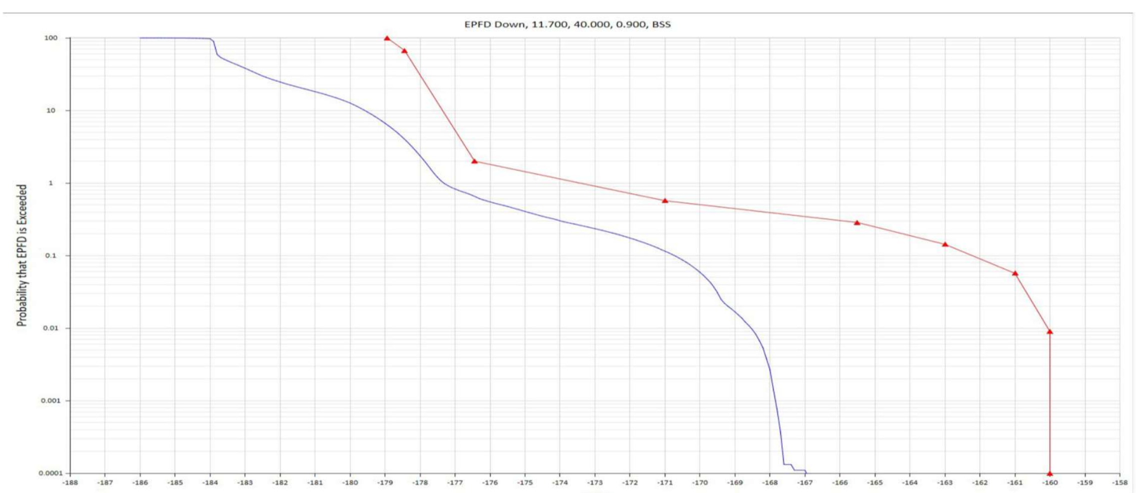
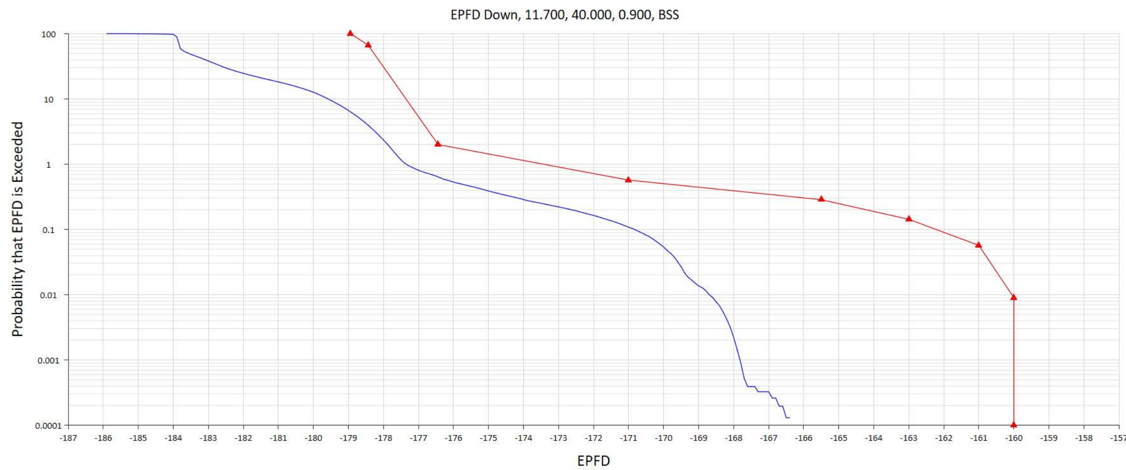
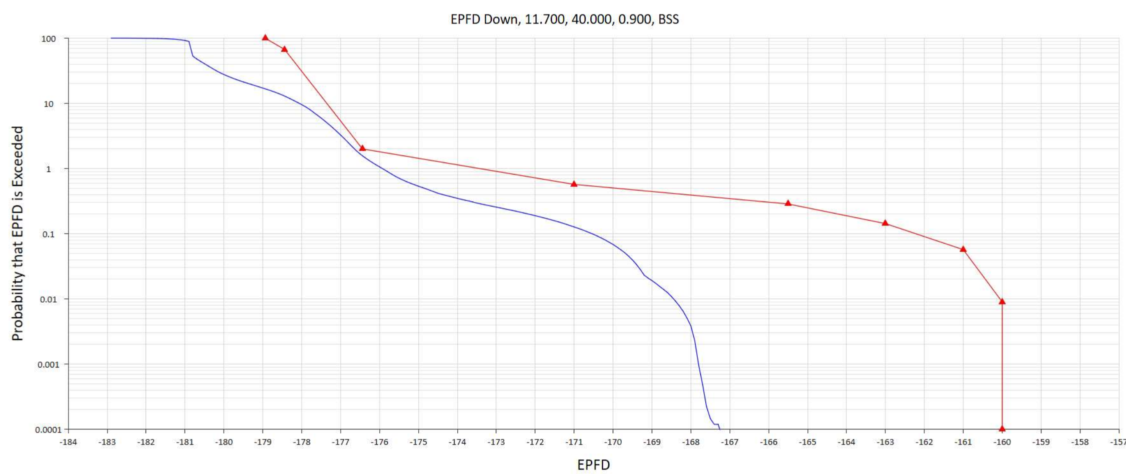


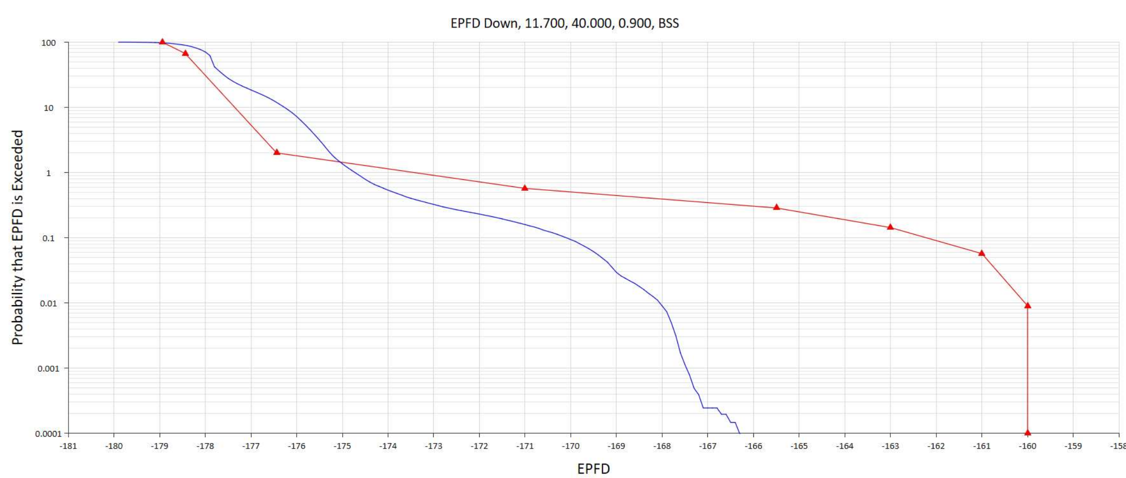
Figure 16a: SpaceX EPFDdn Run – BSS 90 cm antenna



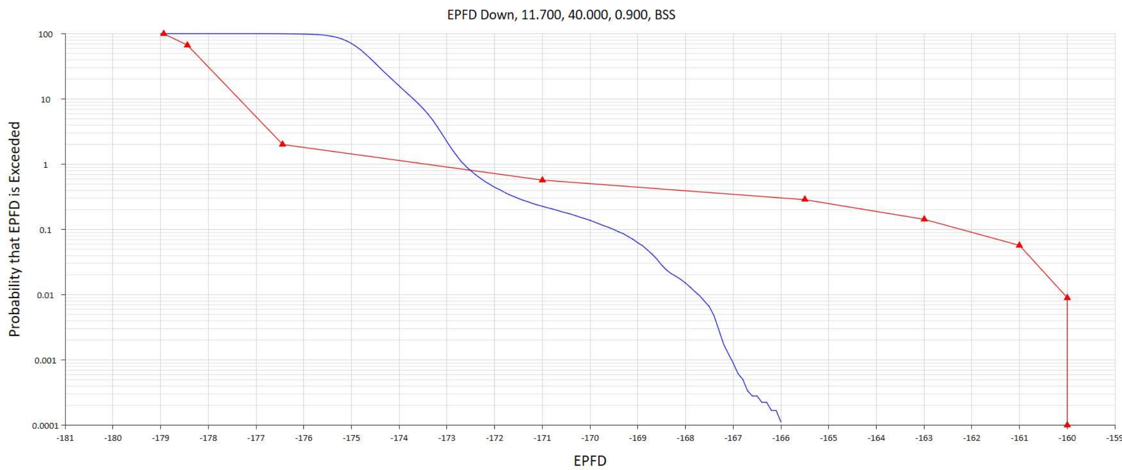
b: Baseline EPFDdn Run – BSS 90 cm antenna



c: Nco =2 EPFDdn Run – BSS 90 cm antenna



d: Nco =4 EPFDdn Run – BSS 90 cm antenna



e: Nco =10 EPFDdn Run – BSS 90 cm antenna

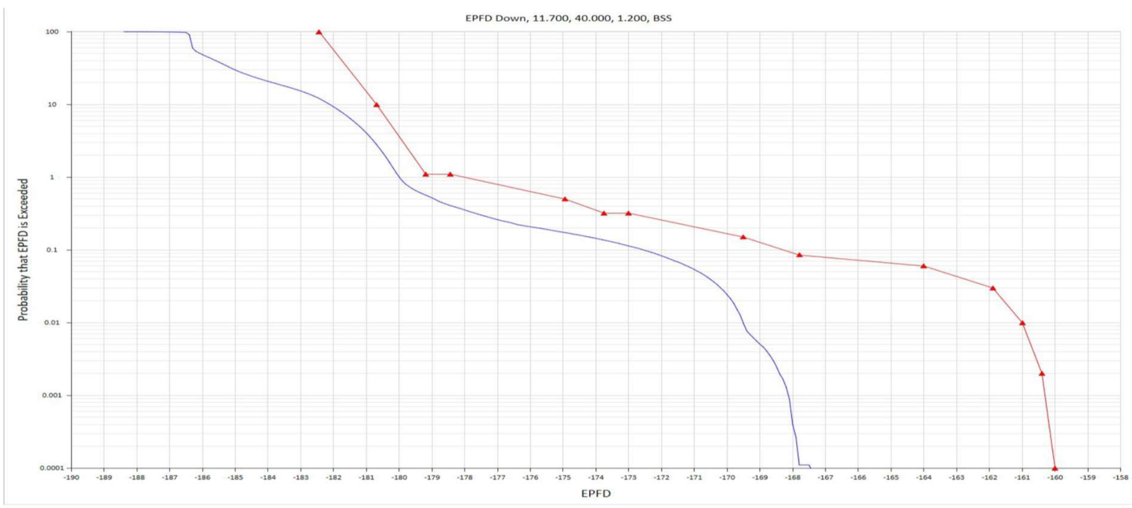
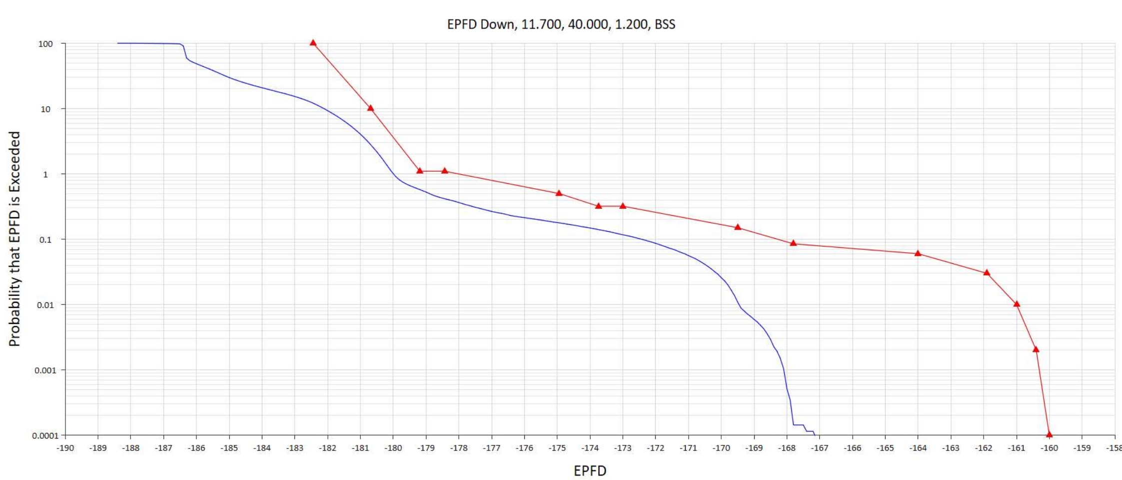
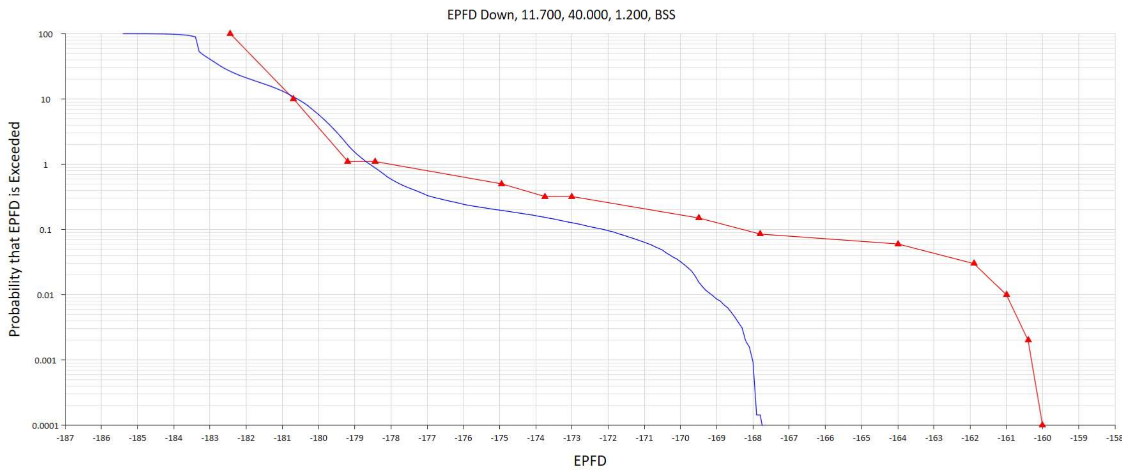


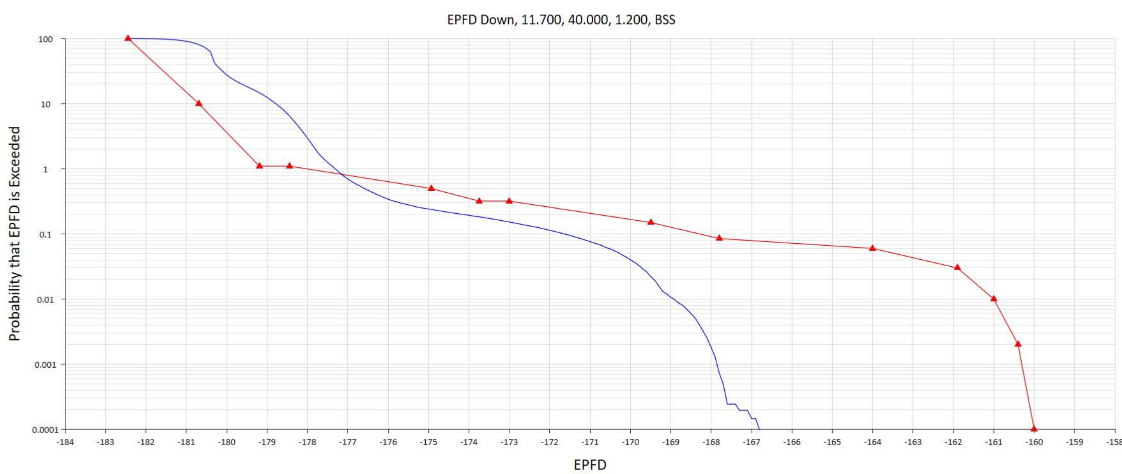
Figure 17a: SpaceX EPFDdn Run – BSS 1.2m antenna



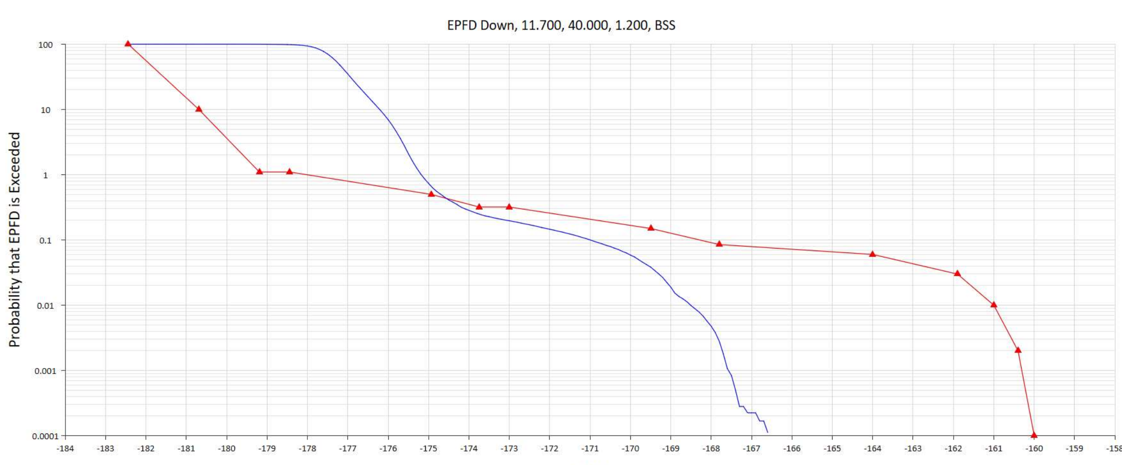
b: Baseline EPFDdn Run – BSS 1.2m antenna



c: NCO = 2 EPFDdn Run – BSS 1.2m antenna



d: NCO = 4 EPFDdn Run – BSS 1.2m antenna



e: NCO = 10 EPFDdn Run – BSS 1.2m antenna

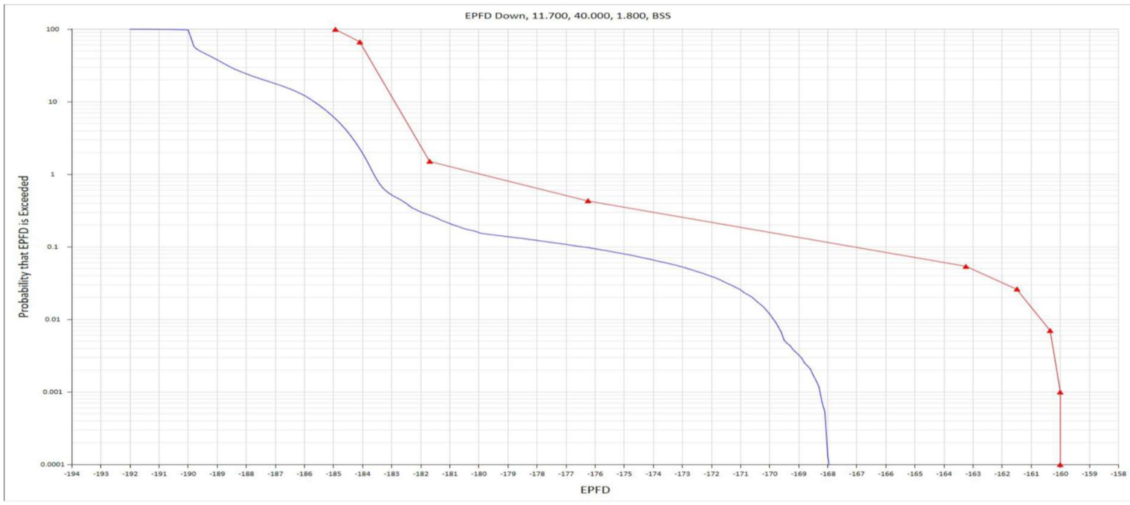
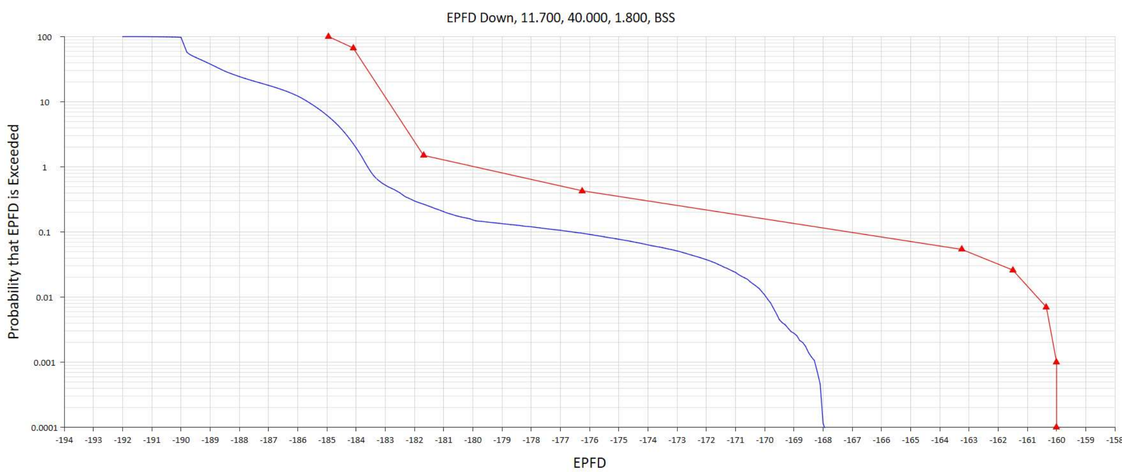
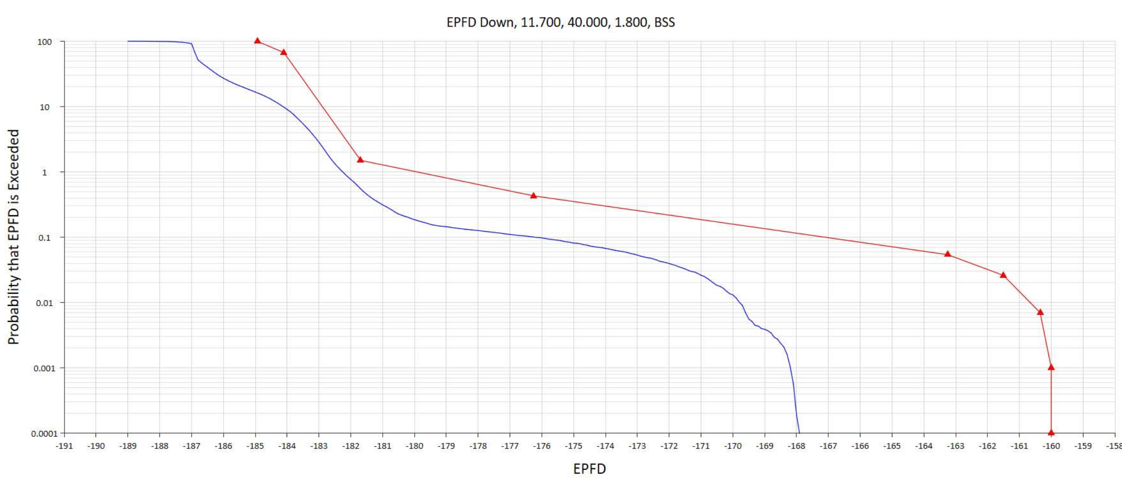


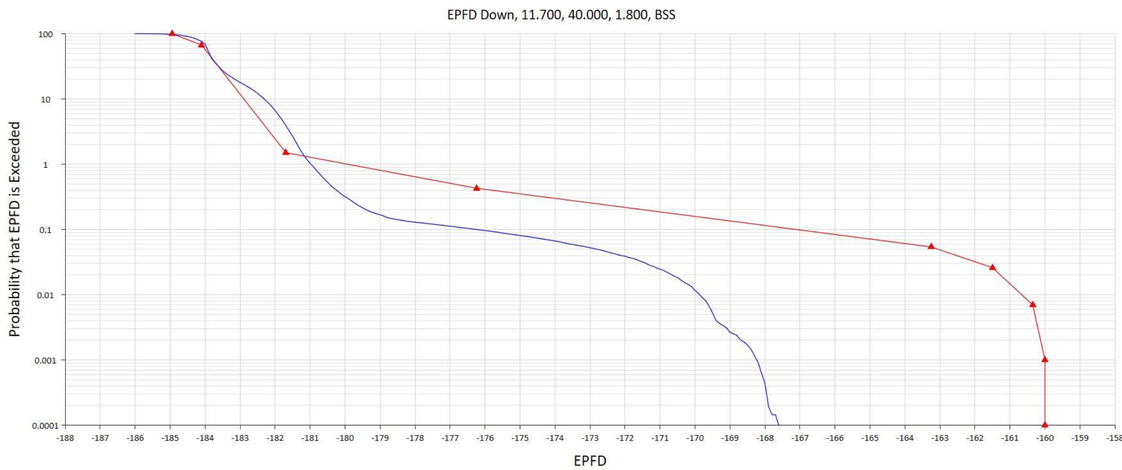
Figure 18a: SpaceX EPFDdn Run – BSS 1.8m antenna



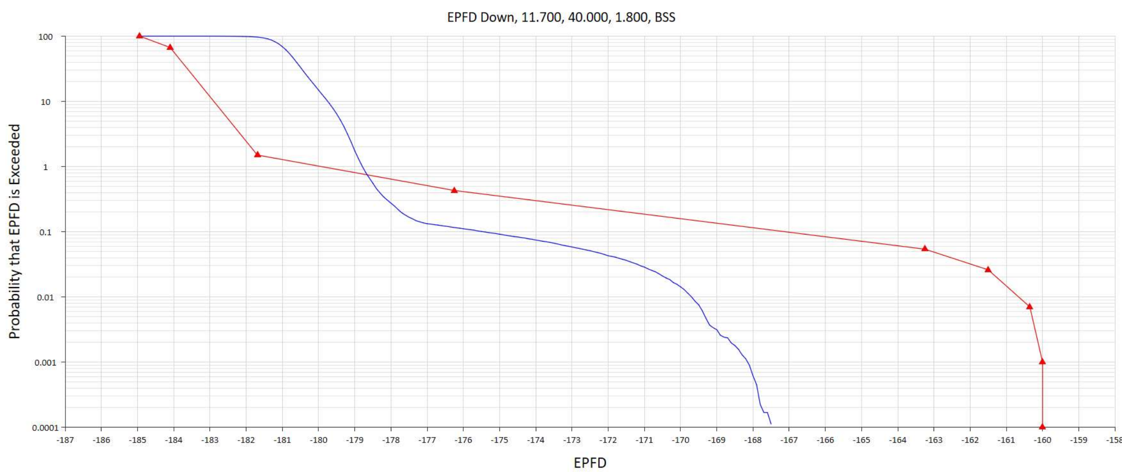
b: Baseline EPFDdn Run – BSS 1.8m antenna



c: NCO =2 EPFDdn Run – BSS 1.8m antenna



d: NCO =4 EPFDdn Run – BSS 1.8m antenna



e: NCO =10 EPFDdn Run – BSS 1.8m antenna

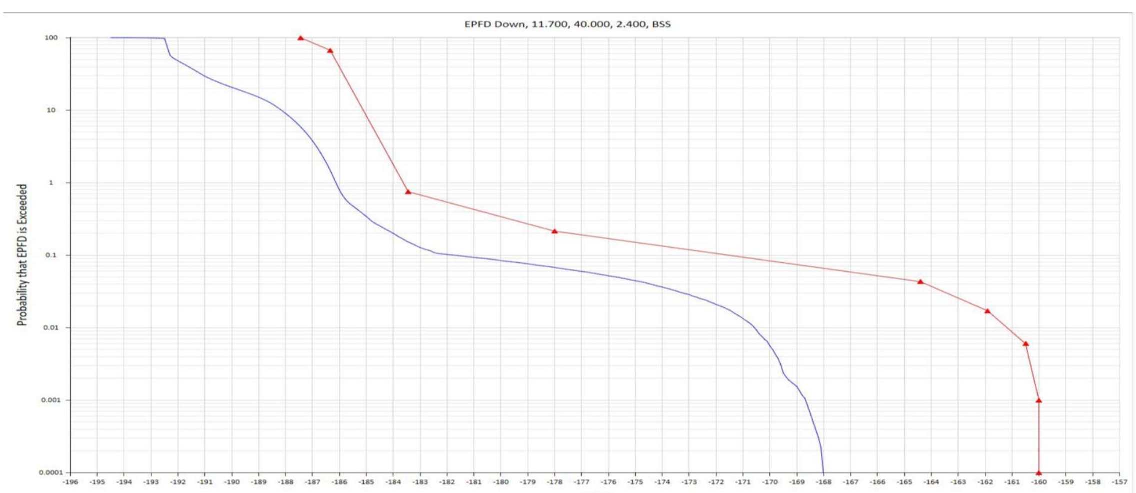
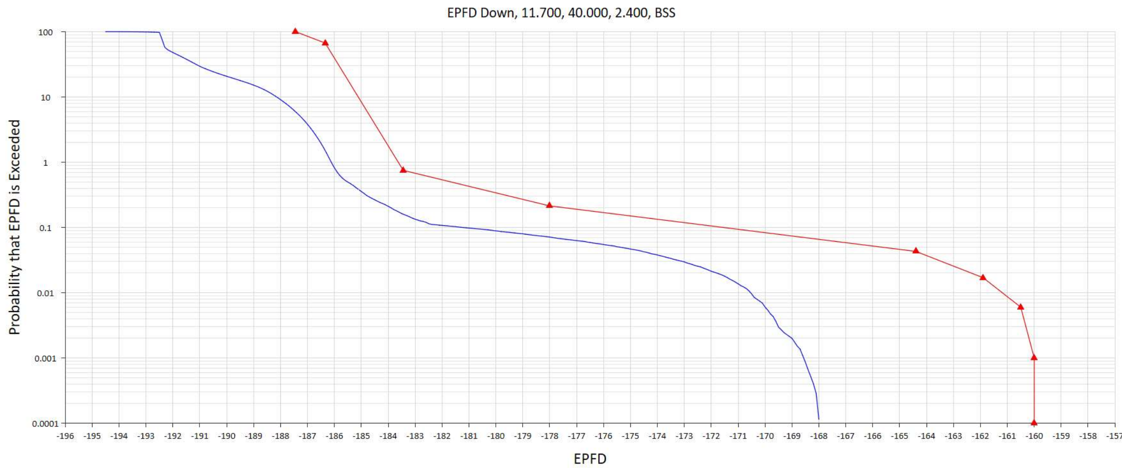
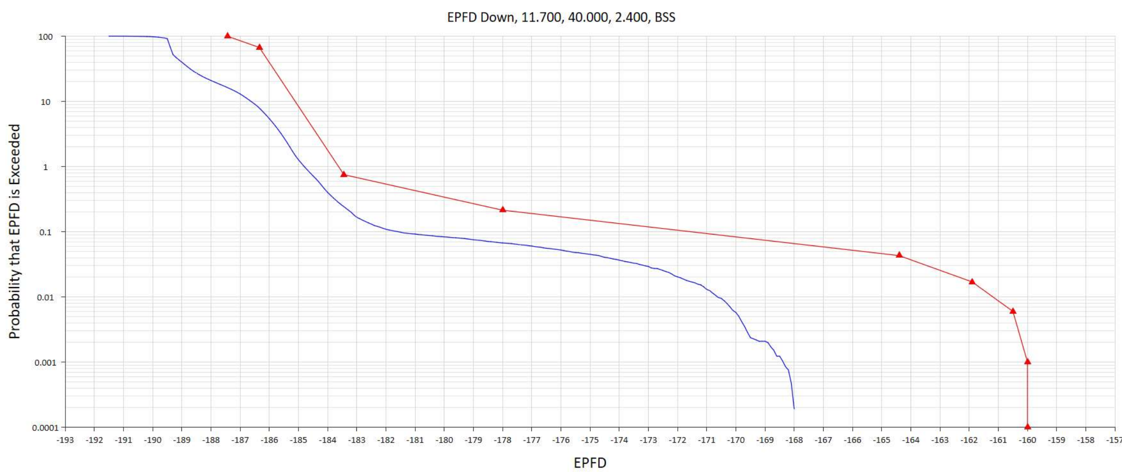


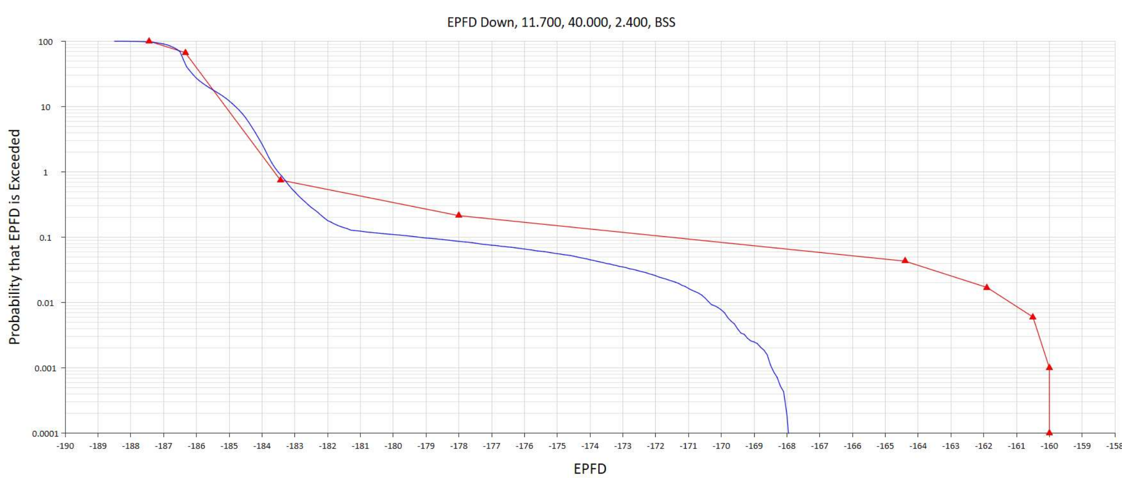
Figure 19a: SpaceX EPFDdn Run – BSS 2.4m antenna



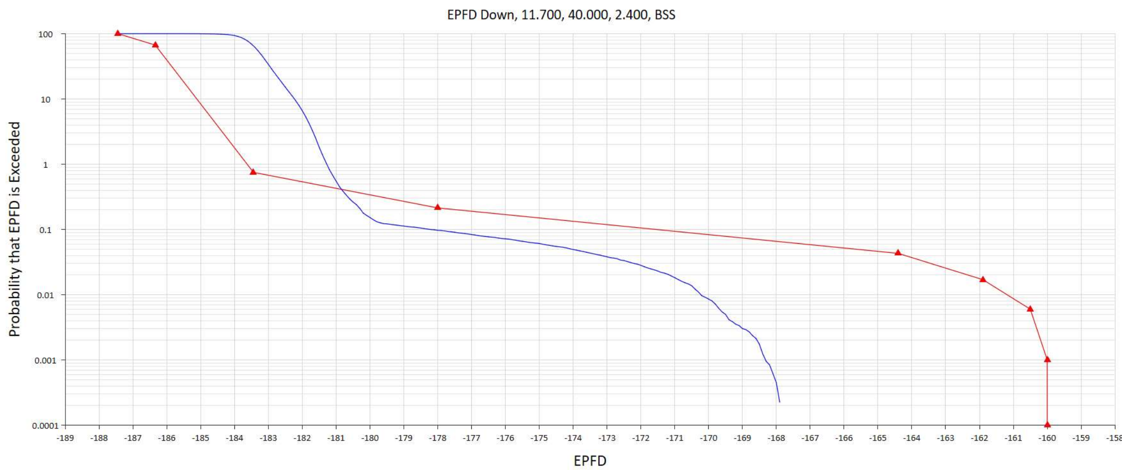
b: Baseline EPFDdn Run – BSS 2.4m antenna



c: NCO =2 EPFDdn Run – BSS 2.4m antenna



d: NCO =4 EPFDdn Run – BSS 2.4m antenna



e: NCO =10 EPFDdn Run – BSS 2.4m antenna

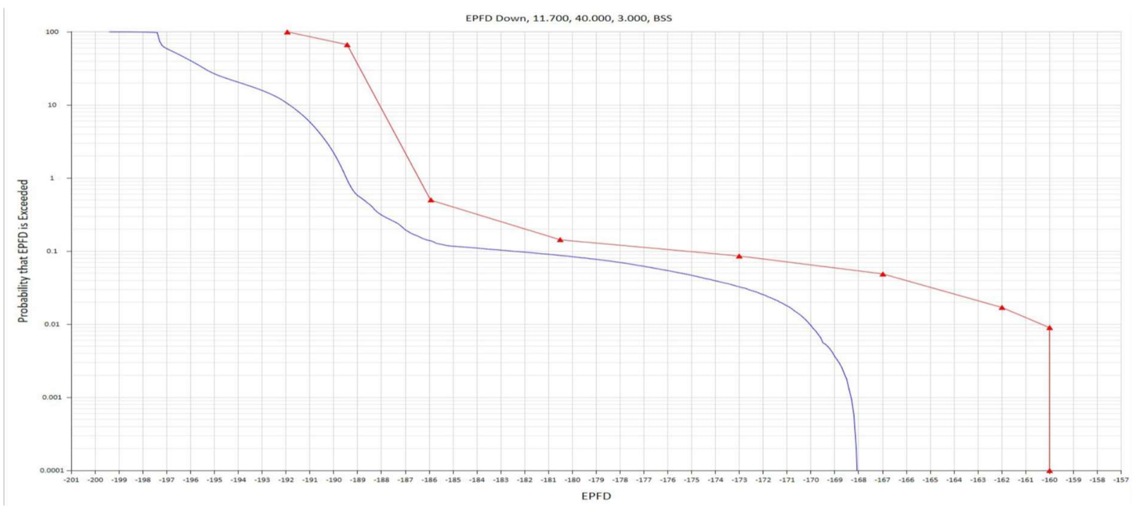
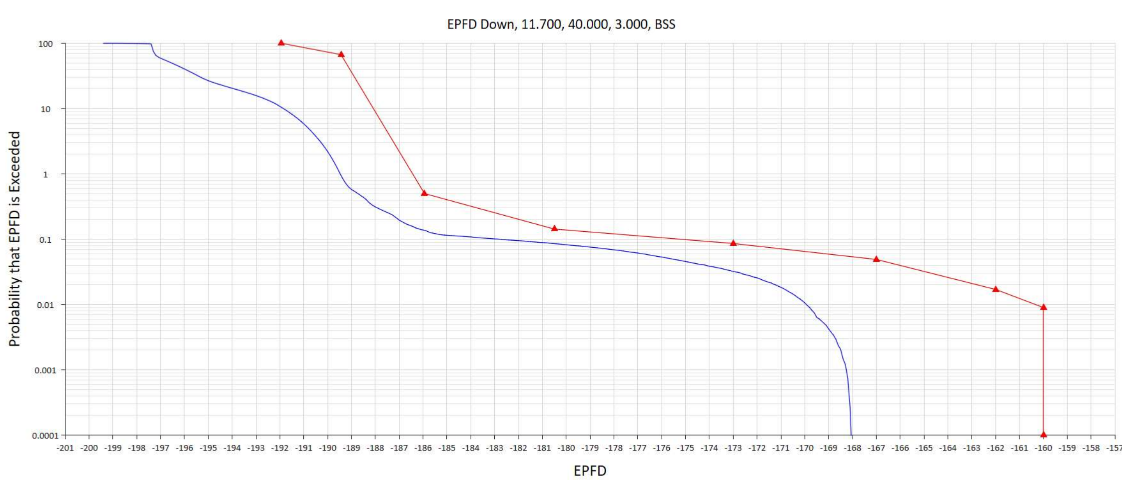
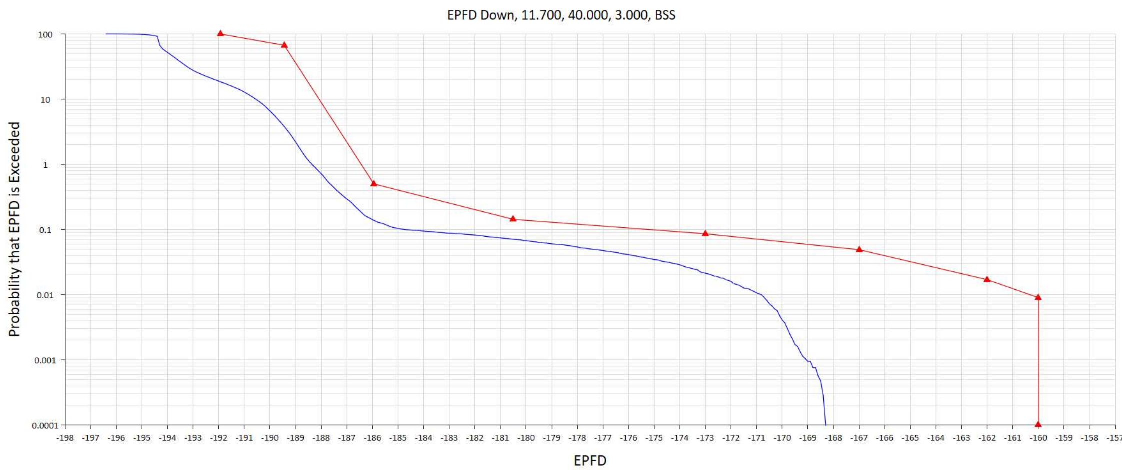


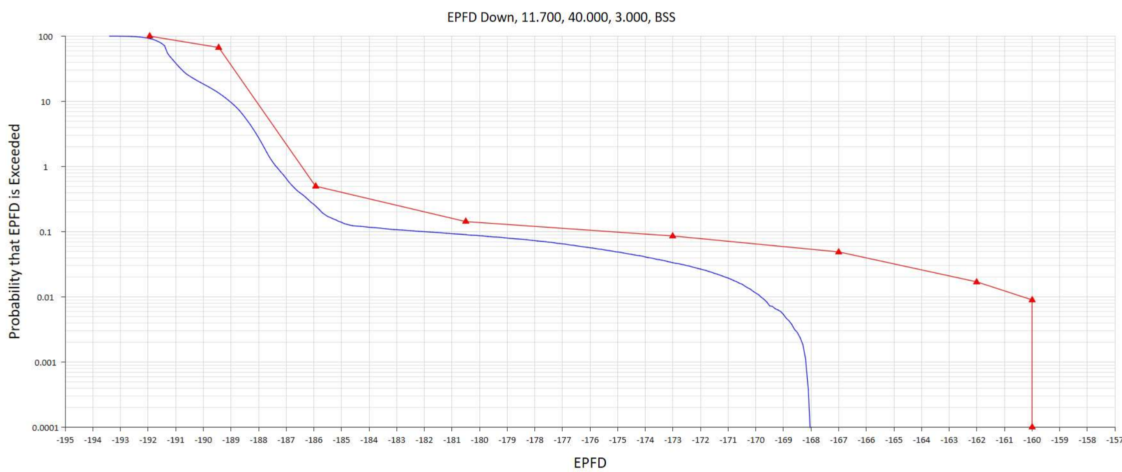
Figure 20a: SpaceX EPFDdn Run – BSS 3m antenna



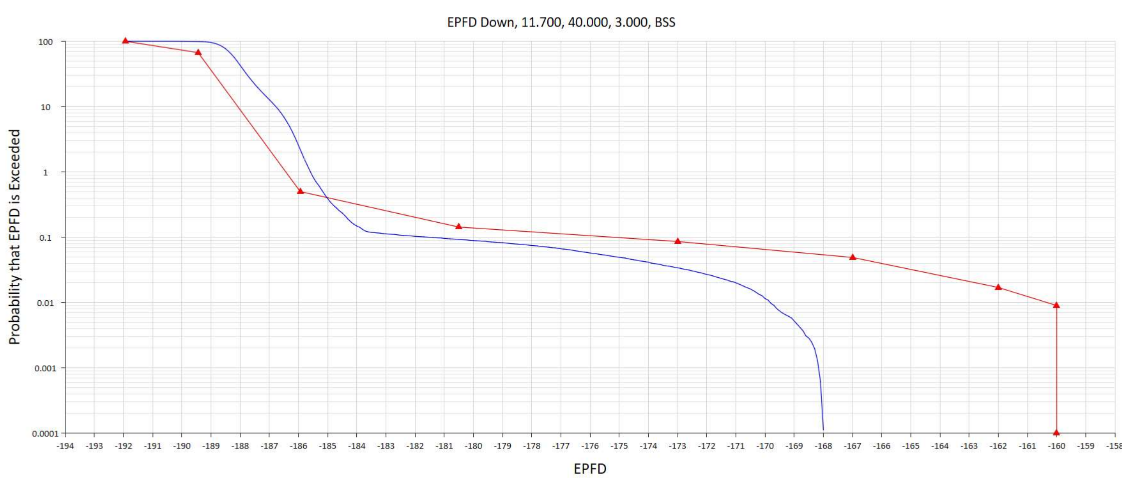
b: Baseline EPFDdn Run – BSS 3m antenna



c: NCO =2 EPFDdn Run – BSS 3m antenna



d: NCO =4 EPFDdn Run – BSS 3m antenna



e: NCO =10 EPFDdn Run – BSS 3m antenna

EPFD$_{DN}$ in 10.7-12.7 GHz for FSS GSO ES receive antenna, WCG

We used the VisualiseEPFD debug tool to see where the contributions to the total EPFD were generated. As we suspected, for the baseline case, with Nco = 1, a single satellite causes most of the EPFD, and that is the one that is located outside the exclusion zone, and where the GSO earth station antenna provides the least amount of off-axis rejection. There are many other NGSO satellites contributing to the total EPFD, but these satellites in the exclusion zone have low PFD – based on SpaceX's declared values, so really contribute little to the total EPFD compared to the Nco satellite(s) that are outside the exclusion zone.

The results for EPFDdn into FSS earth stations are contained in Figures 21 through 24, as indicated in the Table below.

EPFD	SpaceX	Baseline	Nco =2	Nco =4	Nco =10
Dn FSS 0.6	Fig 21a	Fig 21b	Fig 21c	Fig 21d	Fig 21e
Dn FSS 1.2	Fig 22a	Fig 22b	Fig 22c	Fig 22d	Fig 22e
Dn FSS 3.0	Fig 23a	Fig 23b	Fig 23c	Fig 23d	Fig 23e
Dn FSS 10.0	Fig 24a	Fig 24b	Fig 24c	Fig 24d	Fig 24e

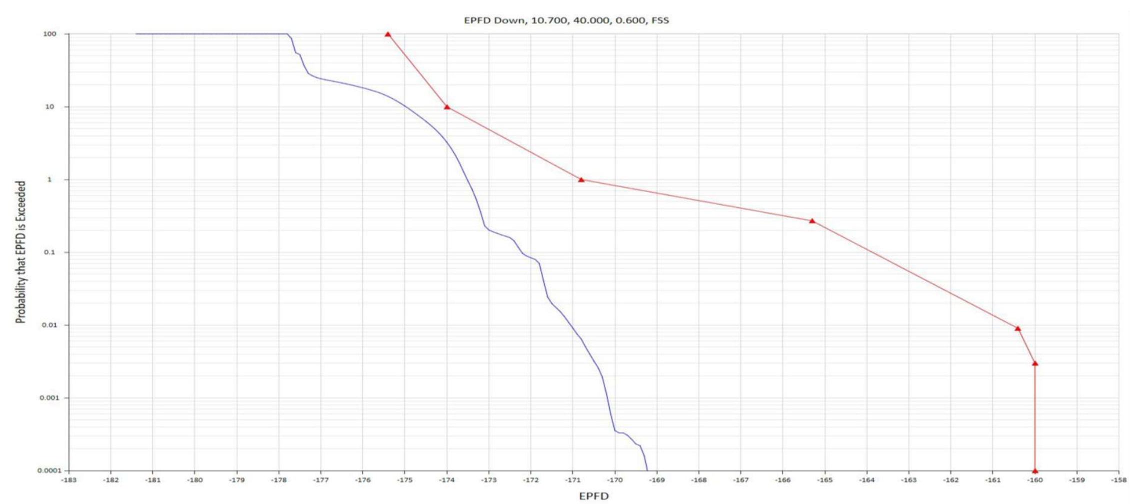
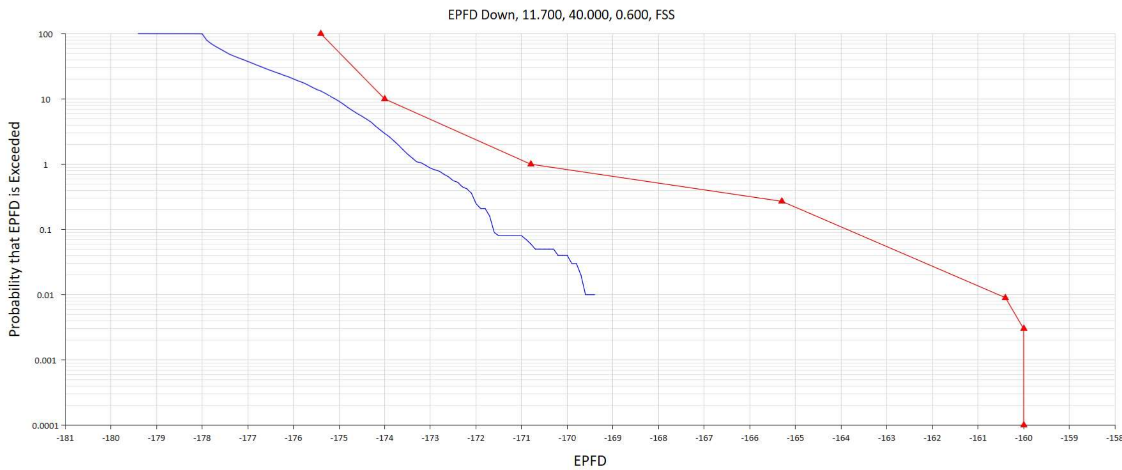
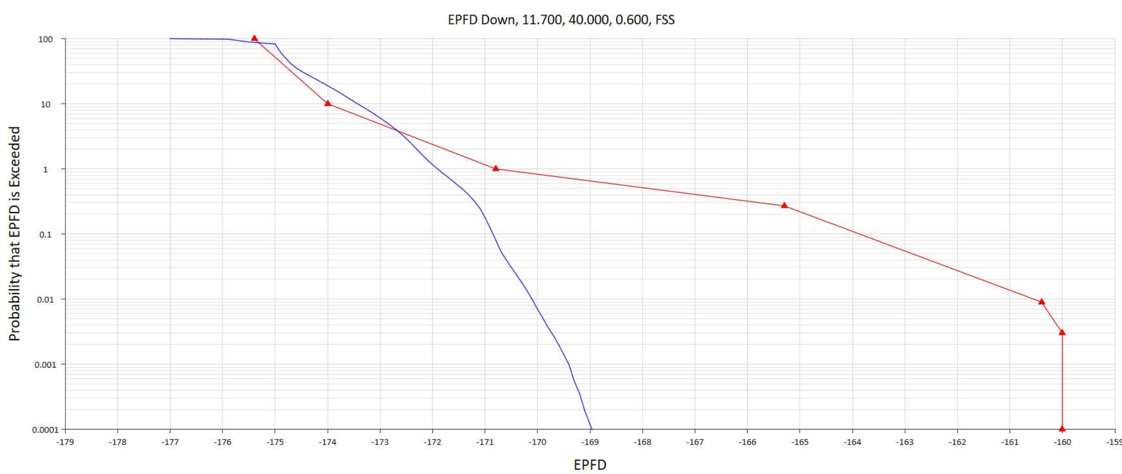


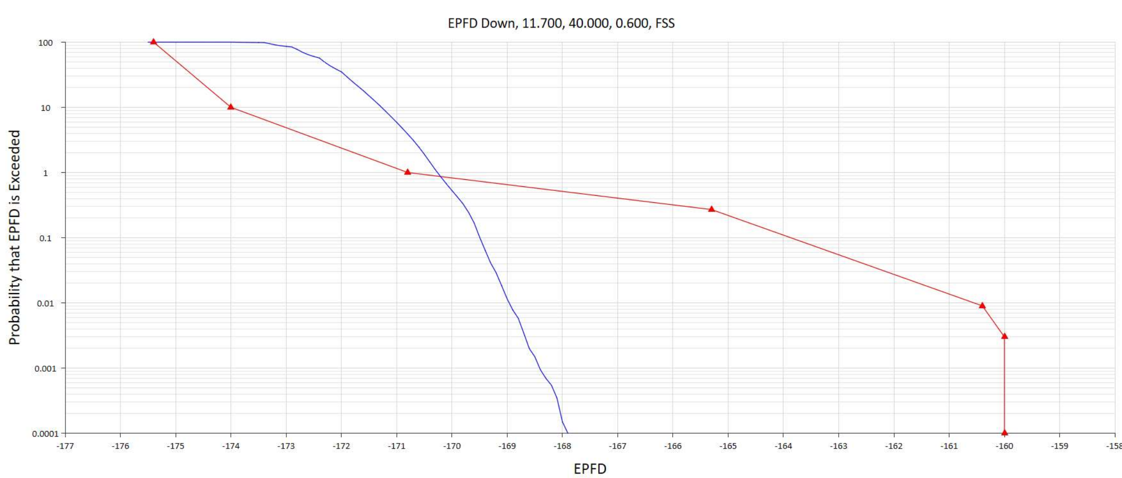
Figure 21a: SpaceX EPFDdn Run – FSS 60cm antenna



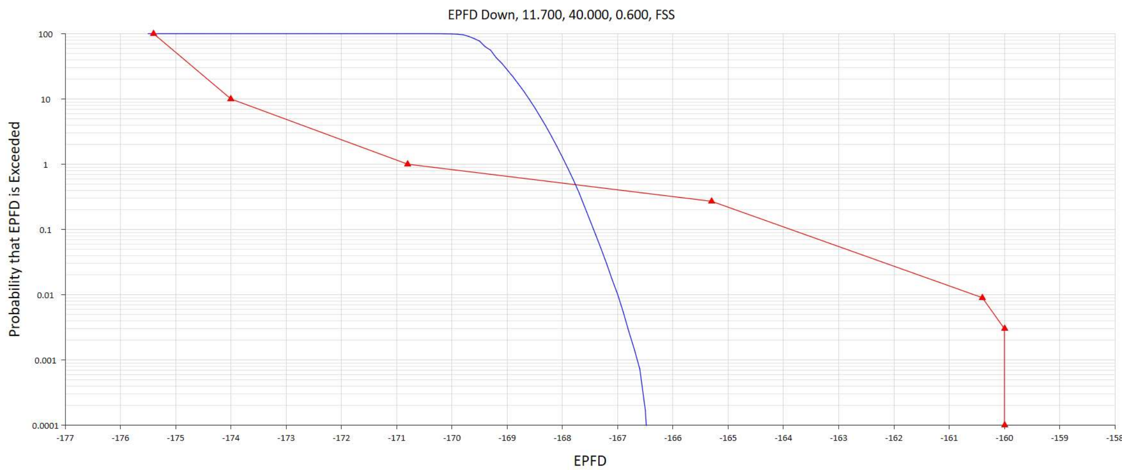
b: Baseline EPFDdn Run – FSS 60cm antenna



c: NCo = 2 EPFDdn Run – FSS 60cm antenna



d: NCo = 4 EPFDdn Run – FSS 60cm antenna



e: NCo = 10 EPFDdn Run – FSS 60cm antenna

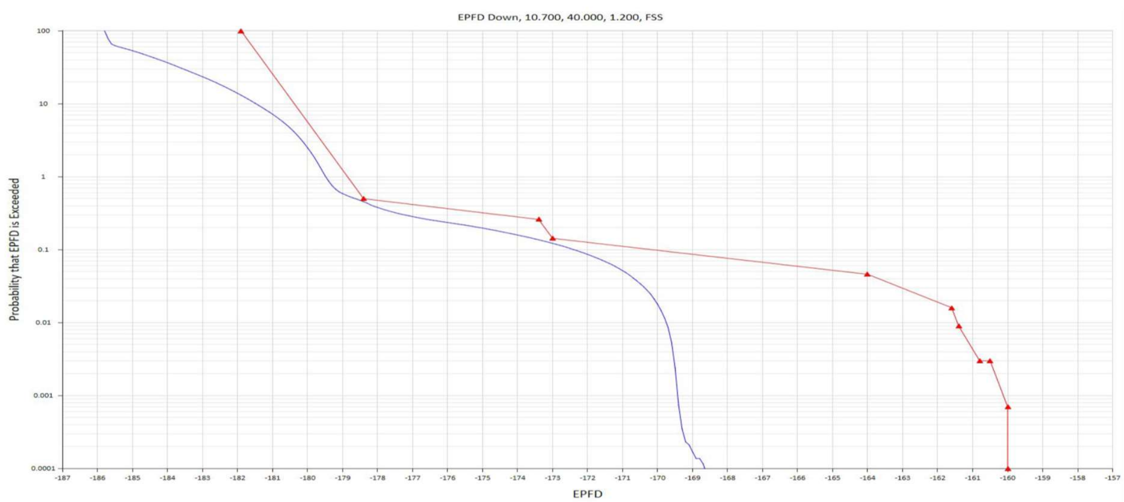
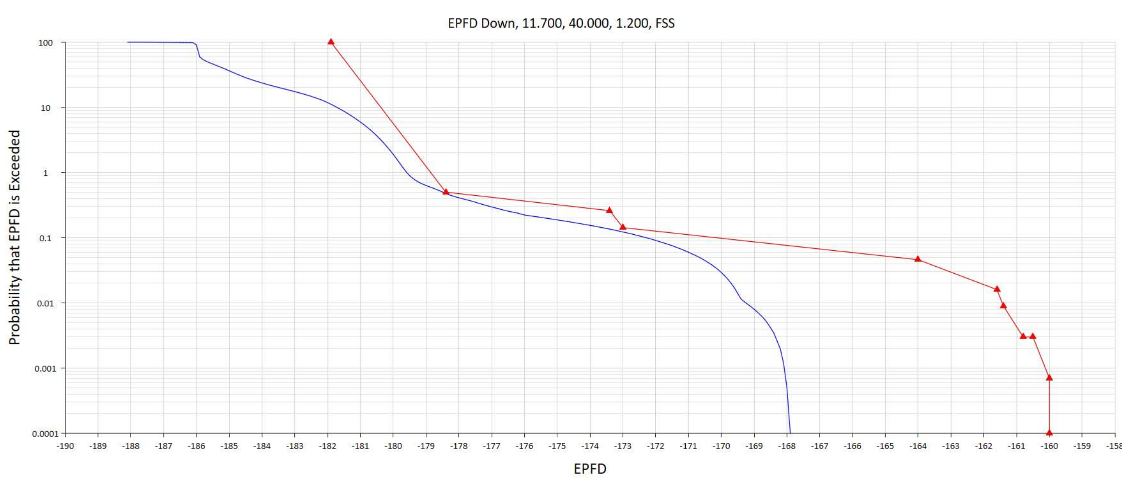
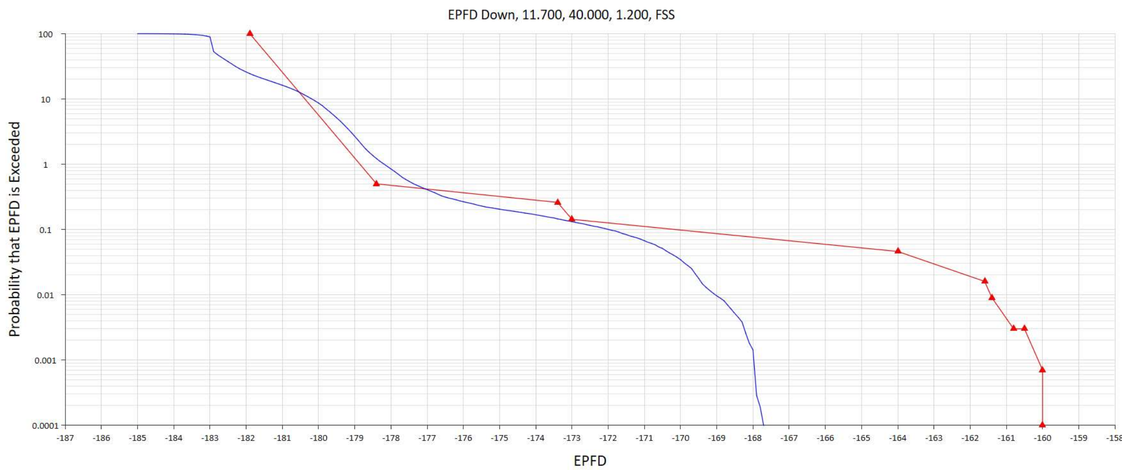


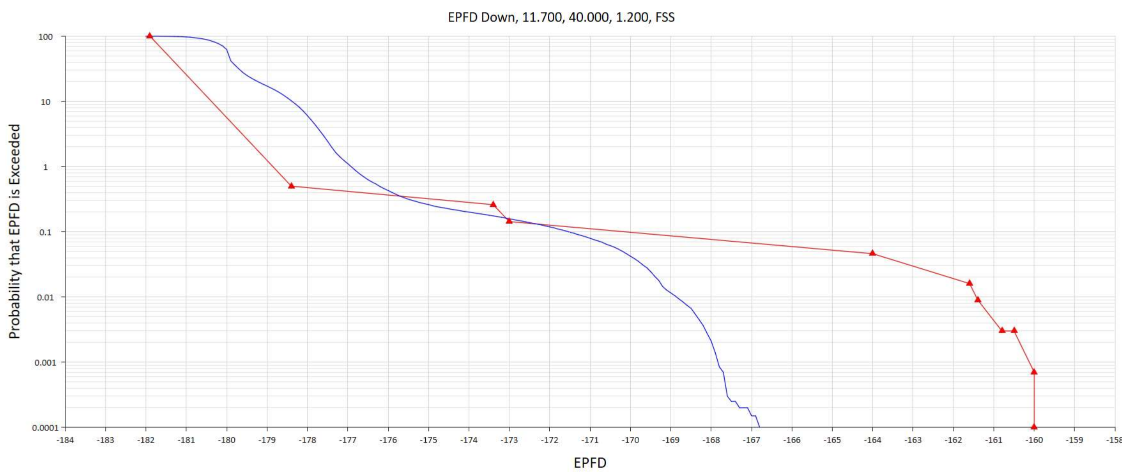
Figure 22a: SpaceX EPFDdn Run – FSS 1.2m antenna



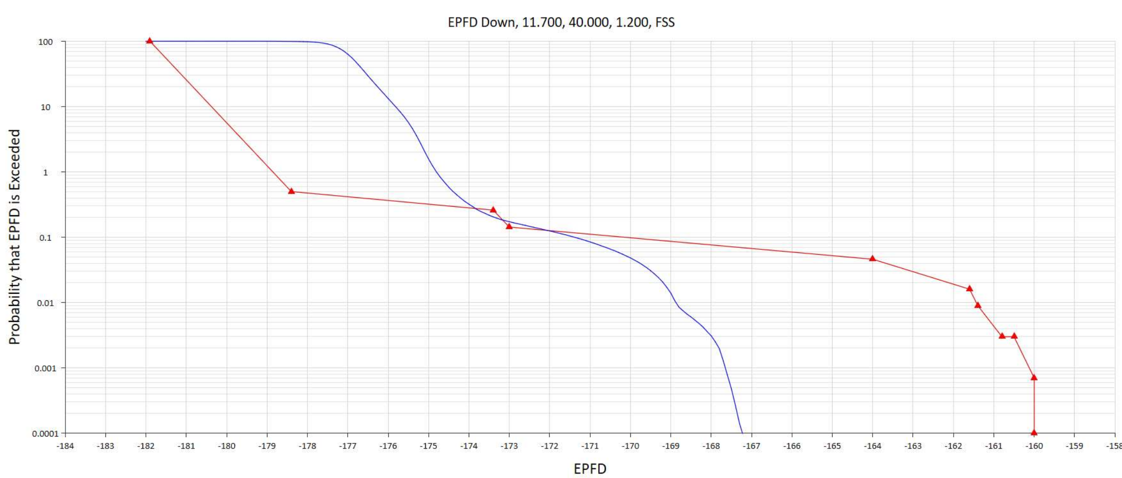
b: Baseline EPFDdn Run – FSS 1.2m antenna



c: NCo = 2 EPFDdn Run – FSS 1.2m antenna



d: NCo = 4 EPFDdn Run – FSS 1.2m antenna



e: NCo = 10 EPFDdn Run – FSS 1.2m antenna

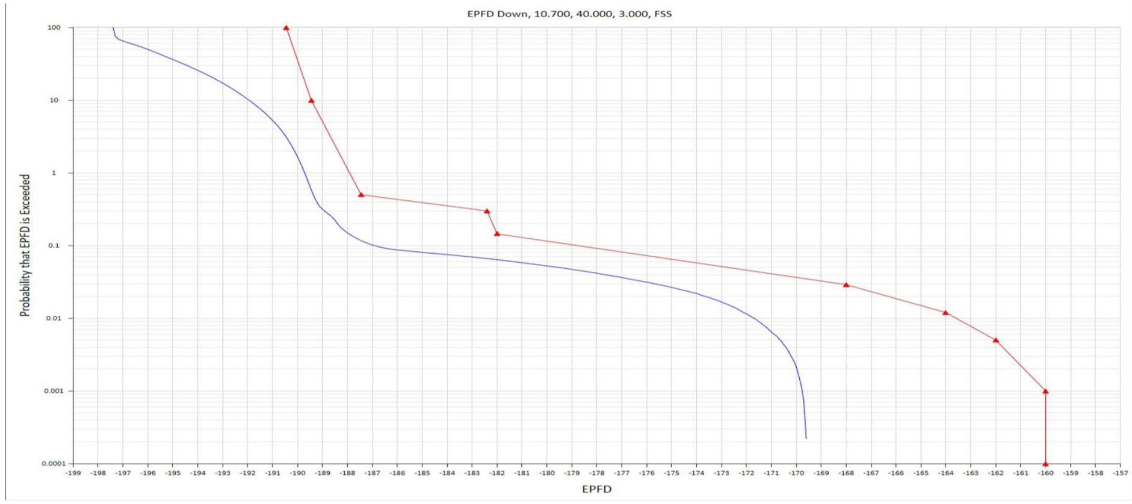
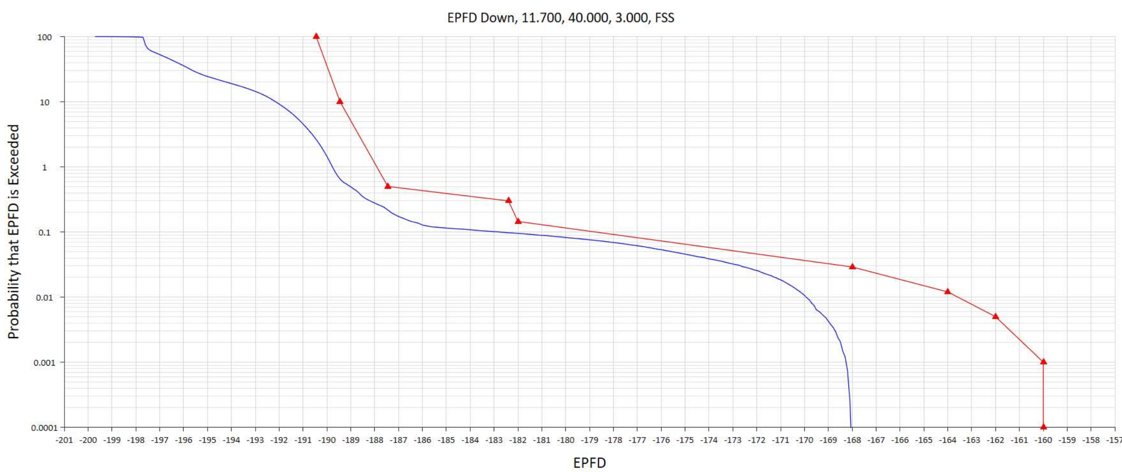
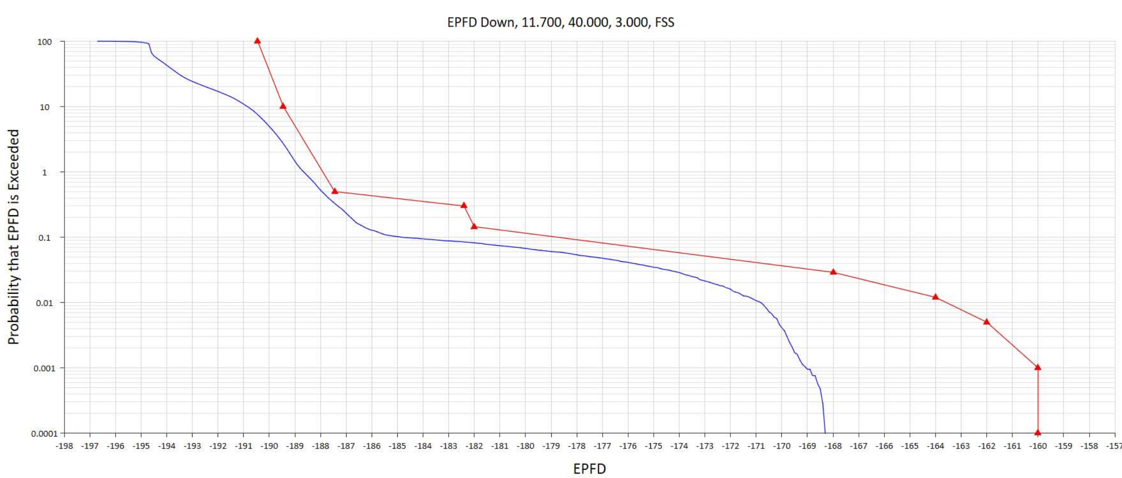


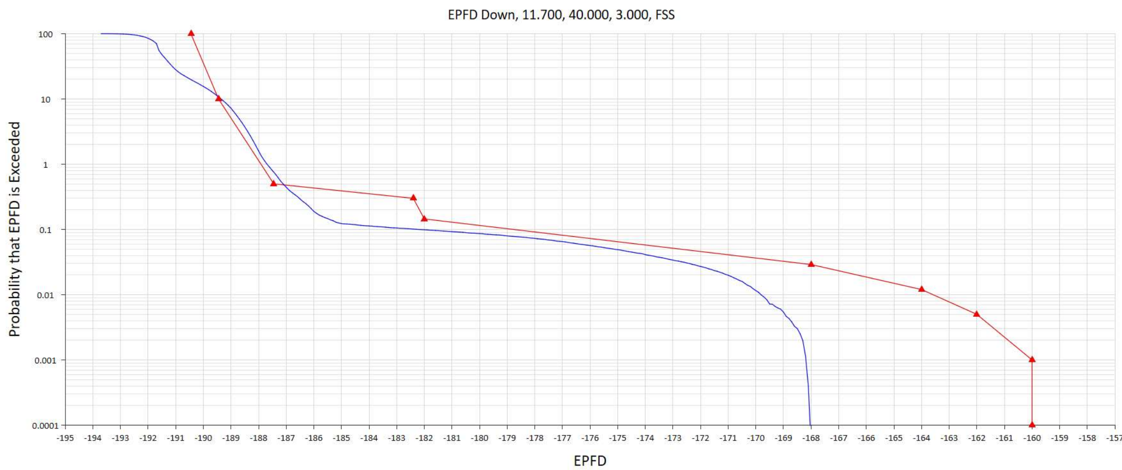
Figure 23a: SpaceX EPFDdn Run – FSS 3m antenna



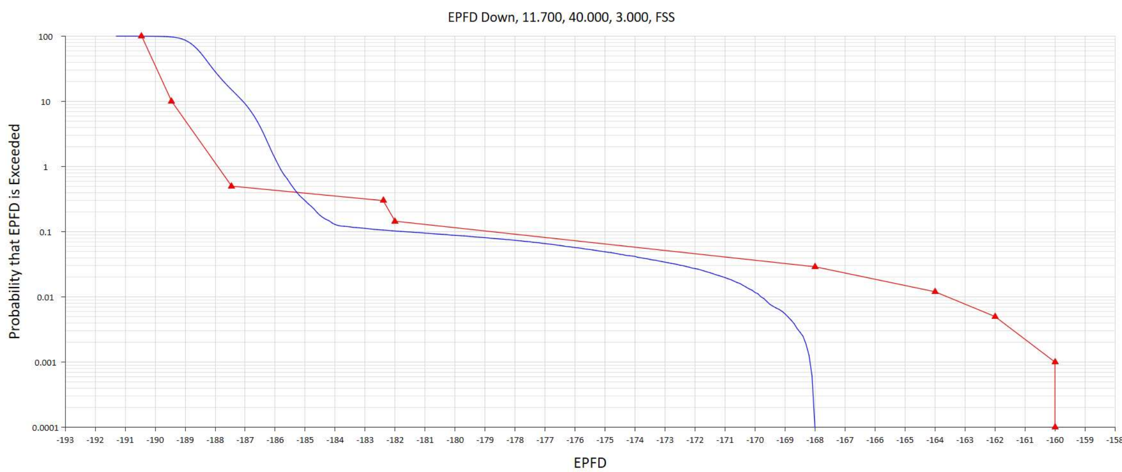
b: Baseline EPFDdn Run – FSS 3m antenna



c: NCo = 2 EPFDdn Run – FSS 3m antenna



d: NCo = 4 EPFDdn Run – FSS 3m antenna



e: NCo = 10 EPFDdn Run – FSS 3m antenna

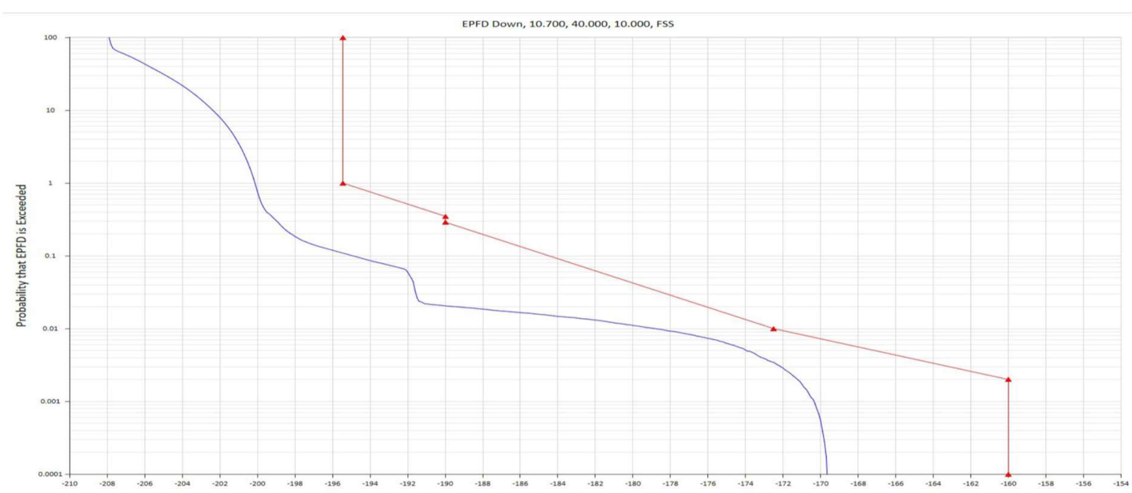
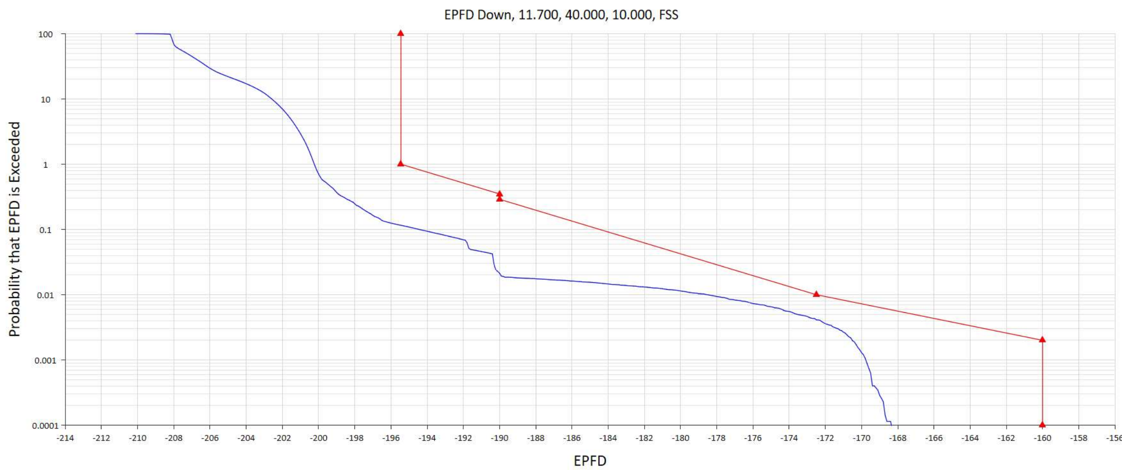
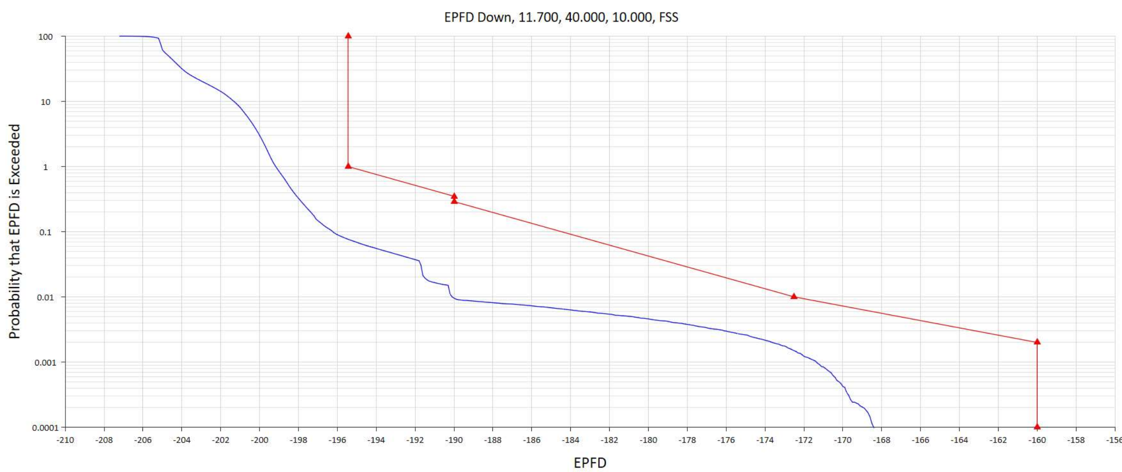


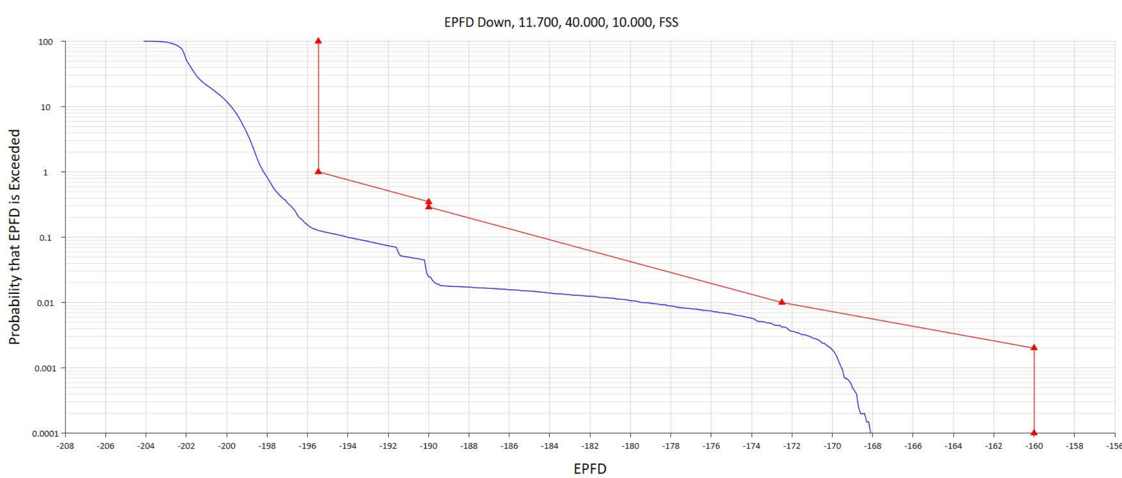
Figure 24a: SpaceX EPFDdn Run – FSS 10m antenna



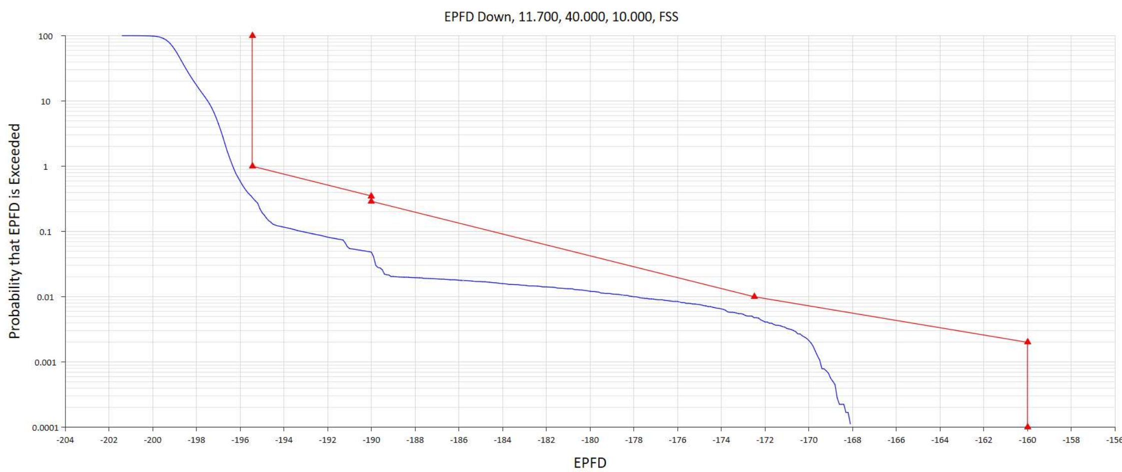
b: Baseline EPFDdn Run – FSS 10m antenna



c: NCo = 2 EPFDdn Run – FSS 10m antenna



d: NCo = 4 EPFDdn Run – FSS 10m antenna



e: NCo = 10 EPFDdn Run – FSS 10m antenna

EPFDis (10.7-11.7 GHz)

EPFD$_{IS}$ in 10.7-11.7 GHz band to protect Regions 1 and 3 FSS uplinks

Figure 25 below shows the EPFD$_{IS}$ for NGSO FSS downlinks into the reverse-band FSS Ku-band uplink, which is not a concern for USA operations since the allocation in the earth-to-space direction is only in ITU Region 1. SpaceX provided the results in Figure 25a, which is for the 3rd MOD satellite application. We have computed EPFDis for the baseline case only as there is no parameter corresponding to Nco for EPFDis and it is shown in Figure 25b.

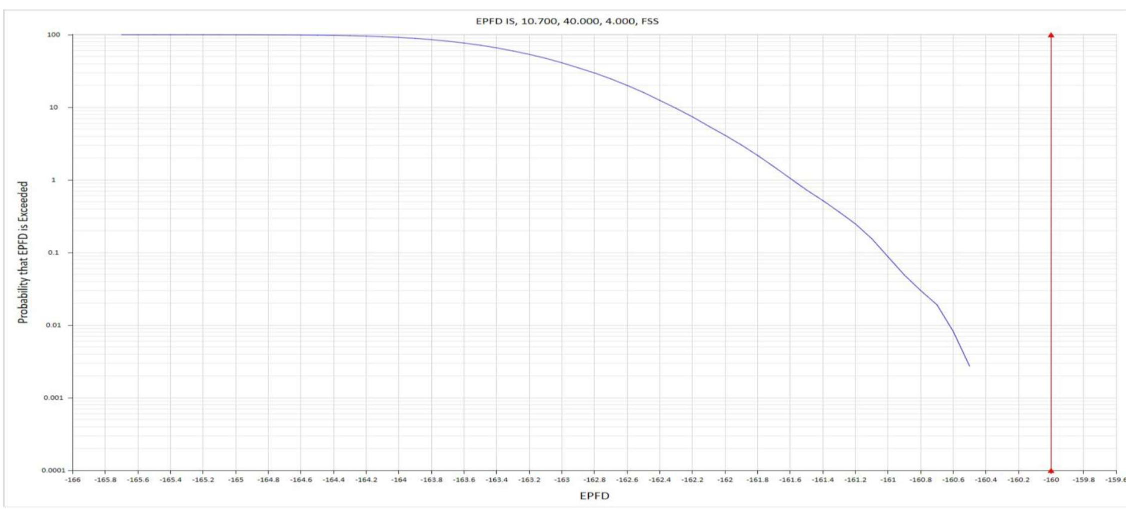
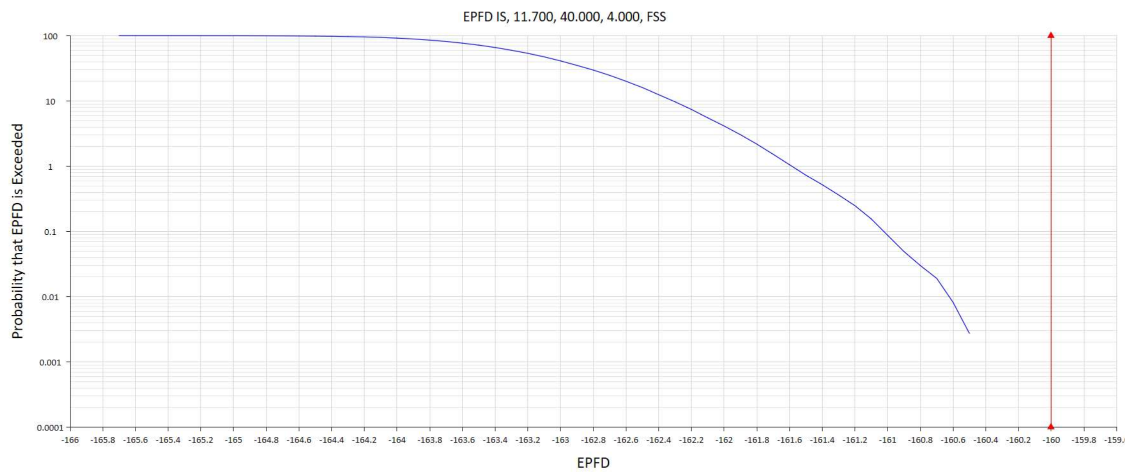


Figure 25a: SpaceX EPFDis Run



b: Baseline EPFDis Run

Results Summary

As can be seen, both the results provided by SpaceX in its FCC filing and the proposed FCC 3rd MOD constellation as modeled – based on the information provided by SpaceX to date – could meet all the EPFD limits when using the stated value for Nco = 1 (nbr_op_sat for downlink, and nbr_sat_td for uplink), corresponding to a single serving satellite outside the GSO exclusion zone for each frequency sub-band and for any location. Our results match quite well with the curves presented by SpaceX as part of its 3rd MOD application. However, increasing the value for Nco's even to a value of 2, clearly would violate some of the EPFD limits, namely for the small antennas, like the ones used by DISH, such as the 45cm and 60cm BSS earth stations and the 60cm and 1.2m FSS antennas.

When increasing the Nco value to 4 or 10, almost all EPFDdn limits are exceeded, with about 1 to 3 dB excess for Nco = 4, and up to 5 dB for Nco = 10.

It should be noted that, for systems with steerable antennas like SpaceX, the PFD mask is really an envelope of the maximum predicted values, but the "serving" satellite, as determined by the software and the Recommendation ITU-R S.1503-2, may not be the worst-interferer in an actual operational sense. This is because the algorithm does not take into account beam steering and switching strategy, but always uses only the user-specified "Nco" possible interfering source(s) that are located outside the GSO avoidance angle that yield highest EPFD, plus all those that are within the GSO avoidance area. The software will *underestimate* the EPFD if there are several co-frequency beams that serve an area whereby the maximum aggregate PFD is higher than the single beam PFD. As mentioned also, it does not take into account all other satellites in view of the victim GSO receive earth station which will also contribute to an increased EPFD due to their co-frequency beams. The actual increase will depend on where their beams are positioned relative to the GSO earth station and their actual PFD towards the GSO earth station.

This study clearly shows that there is a significant impact depending on the value chosen for the simultaneous number of co-frequency satellites operating outside the GSO exclusion zone (Nco) that can contribute to the EPFD into a given GSO earth station location. It is impossible to accurately model how demand will spread geographically speaking, but it is certainly expected that there will be areas that require much more traffic than others. Given that ITU-R Recommendation S.1503-2 uses only the "Nco" satellites specified by the user and ignores the EPFD contribution from all other satellites outside the exclusion zone, whether or not their beams overlap the "Nco" satellite(s) generating the highest EPFD at any instant in time, selecting Nco = 1 prevents the inclusion of EPFD contribution from these other satellites in the overall EPFD thereby resulting in an underestimation of the actual interference. The specified value of Nco =1 is therefore unrealistic, as it completely ignores the EPFD contribution of all other visible satellites.

As was recognized by ITU-R WP4A[14], the original recommendation was not developed for steerable beams, but rather was based on fixed beams or fixed cells, where the contribution of each satellite in view could be properly assessed. With the current software, one can either under-estimate the EPFD by setting the Nco = 1, or over-estimate it by setting the Nco >> design value. We firmly believe that, even if SpaceX makes an operational decision to have no more than 2 co-coverage satellites, that Nco = 4 to 10 would represent an effective approximation of the levels of interference that could be expected. If, on the other hand, SpaceX allows multiple satellites to position co-frequency beams to serve multiple users at a given location, for example, to serve multiple users in a large town, mining camp, logging camp, ship or aircraft, or large vacation resort, all of which may not be served by terrestrial means, the EPFD levels may even exceed those computed in this study.

Conclusion

This study has demonstrated that the EPFD results presented by SpaceX to the FCC in its 3rd MOD application, and those assessed by the ITU, do not represent a realistic scenario, since the current version of the software only assumes a single satellite can serve any given point on the Earth's surface on a given channel/frequency, and does not model the impact of other satellites which may also cover the same geographic area or other areas, and using the same channel. By ignoring the impact of many satellites in view of the GSO earth station that cover adjacent areas which could increase EPFD levels significantly, SpaceX erroneously concludes that the ITU RR Article 22 EPFD limits are met. The study also shows, at least for two example GSO earth stations, an increase in EPFD values for the 3rd Modification, as compared to the original STEAM-1 filing.

---

[14] During the 2016-2019 study cycle, ITU-R WP4A recognized the issue (*see* Document 4A/63 annex 17), so modified this Recommendation and SG4 approved Recommendation ITU-R S.1503-3 (*see* https://www.itu.int/rec/R-REC-S.1503-3-201801-I/en); however, this version has not yet been implemented in software. Since July 2018 WP4A has carried a working document towards a future revision to Recommendation ITU-R S.1503-3 that would further enhance the treatment of NGSO FSS employing steerable beams.